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Levene et al.

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(54) **IMAGING MEASUREMENT SYSTEM WITH A PRINTED PHOTODETECTOR ARRAY**

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G01T 1/29	(2006.01)
G01T 1/20	(2006.01)

(52) **U.S. Cl.**
CPC ***G01T 1/2985*** (2013.01); ***G01T 1/2018*** (2013.01); ***G01T 1/242*** (2013.01); ***G01T 1/249*** (2013.01)

(58) **Field of Classification Search**
CPC G01T 1/2018; G01T 1/202; G01T 1/2985; G01T 1/242; G01T 1/249; G01T 1/16; G01T 1/20; H01L 27/14601; H01L 31/0322; H01L 27/14658
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,138,167 A	8/1992	Barnes
5,933,168 A	8/1999	Sakai

(Continued)

FOREIGN PATENT DOCUMENTS

JP	1126584 A	5/1989
WO	03/077318	9/2003

(Continued)

OTHER PUBLICATIONS

Yahaya et al., "Fabrication of Photodiode by Screen Printing Technique," ICSE'98 Proc. Nov. 1998, Bangi, Malaysia, p. 254-259. Retrieved from internet [Mar. 9, 2014]; Retrieved from url <http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=781191&tag=1>.*

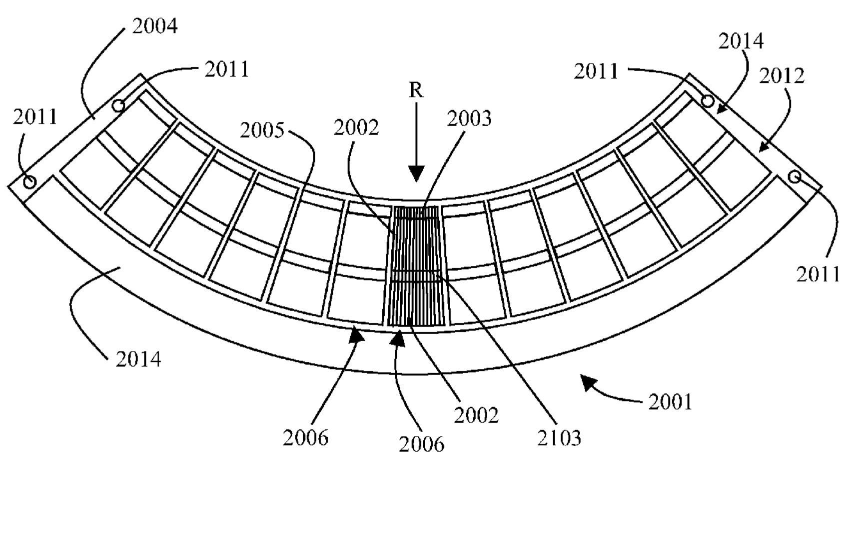
(Continued)

Primary Examiner — Yara B Green

(57) **ABSTRACT**

Low cost large area photodetector arrays are provided. In a first embodiment, the photodetectors comprise an inorganic photoelectric conversion material formed in a single thick layer of material. In a second embodiment, the photodetectors comprise a lamination of several thin layers of an inorganic photoelectric conversion material, the combined thickness of which is large enough to absorb incoming x-rays with a high detector quantum efficiency. In a third embodiment, the photodetectors comprise a lamination of several layers of inorganic or organic photoelectric conversion material, wherein each layer has a composite scintillator coating.

37 Claims, 18 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,462,344	B1 *	10/2002	Joo et al.	250/370.09
6,717,152	B2	4/2004	Izumi	
6,898,265	B1 *	5/2005	Mliner et al.	378/19
6,982,424	B2	1/2006	Vafi et al.	
7,010,088	B2	3/2006	Narayanaswamy et al.	
7,230,247	B2	6/2007	Shibayama	
7,276,749	B2	10/2007	Martin et al.	
7,479,640	B2	1/2009	Misawa	
7,582,506	B2	9/2009	Basol	
2003/0031296	A1	2/2003	Hoheisel	
2003/0200655	A1	10/2003	Vafi et al.	
2004/0016886	A1	1/2004	Ringermacher et al.	
2005/0018810	A1 *	1/2005	Narayanaswamy et al.	378/91
2005/0104000	A1 *	5/2005	Kindem et al.	250/361 R
2005/0113682	A1 *	5/2005	Webber et al.	600/426
2006/0153985	A1	7/2006	Roscheisen et al.	
2007/0075253	A1	4/2007	Misawa	
2007/0163639	A1	7/2007	Robinson et al.	
2007/0163644	A1	7/2007	Van Duren et al.	
2007/0166453	A1	7/2007	Van Duren et al.	
2008/0210877	A1 *	9/2008	Altman et al.	250/366
2008/0237470	A1	10/2008	Loureiro et al.	
2009/0218650	A1	9/2009	Lee	
2010/0193695	A1	8/2010	Yeow et al.	
2010/0220833	A1 *	9/2010	Levene et al.	378/19

FOREIGN PATENT DOCUMENTS

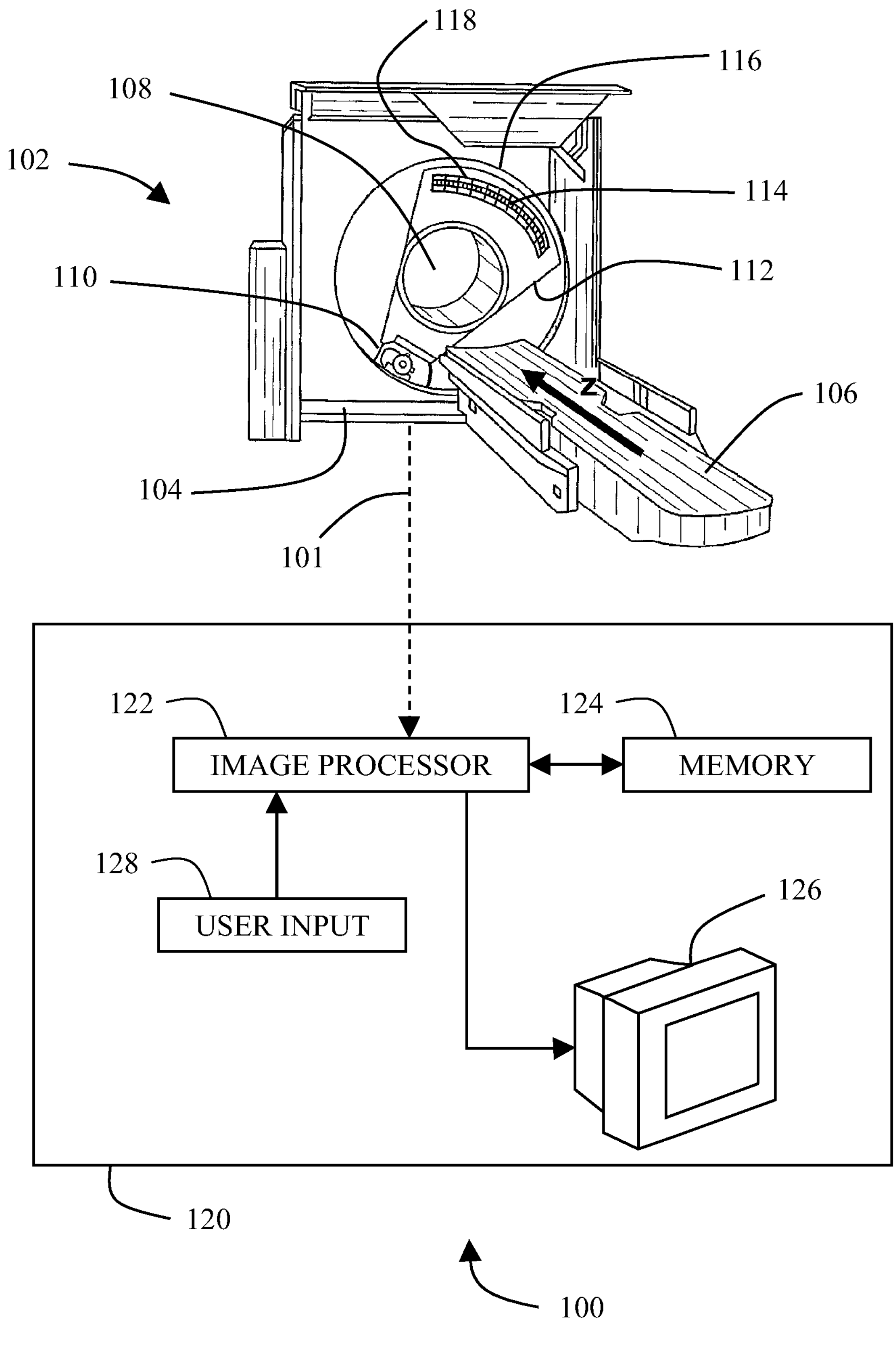
WO	2008033508	A2	3/2008
WO	2009/062311		5/2009
WO	2009083852	A2	7/2009

OTHER PUBLICATIONS

Matsushima, O., et al.; A High-sensitivity Broadband Image Sensor using CuInCaSe2 Thin Films; 2008; IEEE Trans. on International Electron Devices Meeting; 4 pages.

* cited by examiner

FIG. 1


118
116
108
102
114
110
112
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106
104
101
122
124
IMAGE PROCESSOR
MEMORY
128
USER INPUT
126
120
100

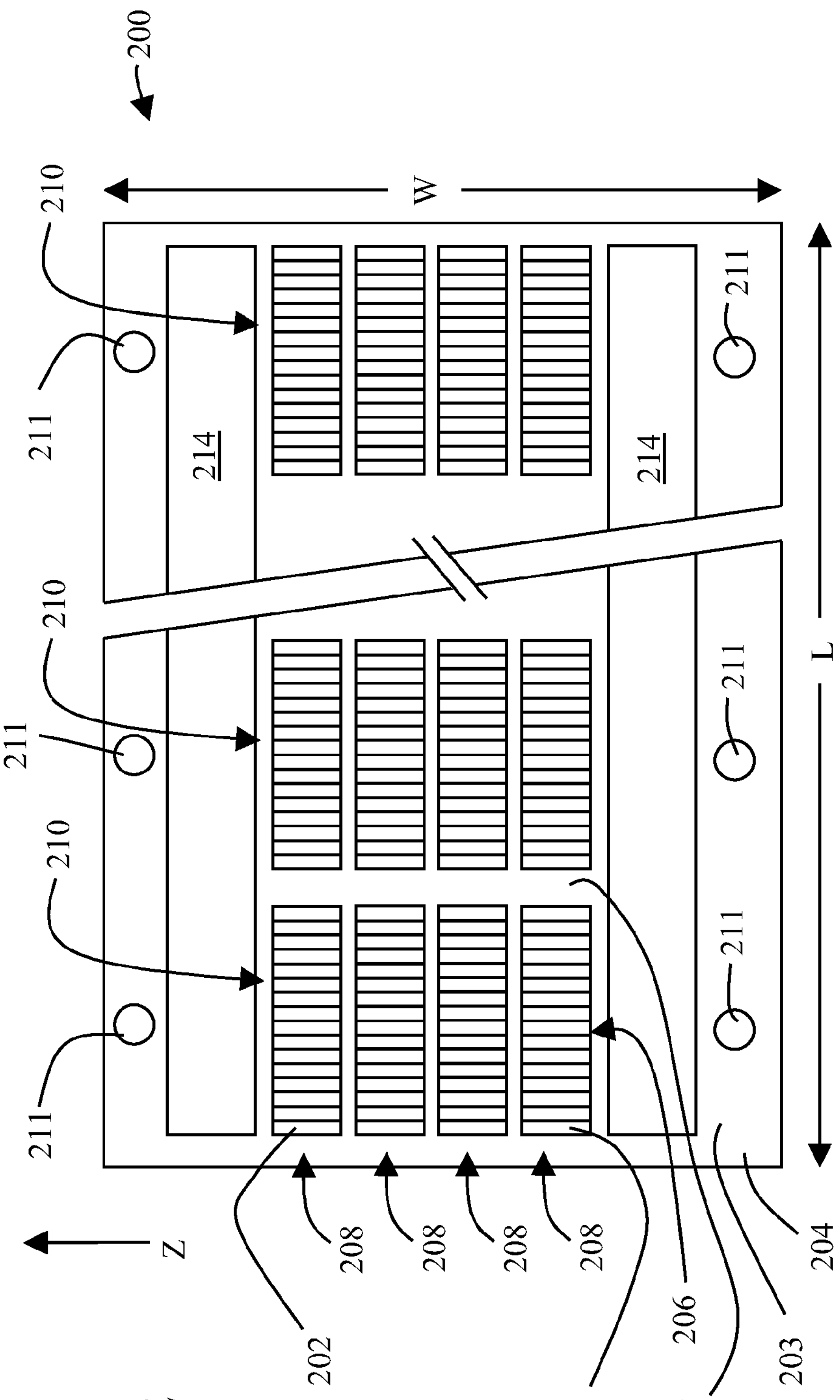


FIG. 2

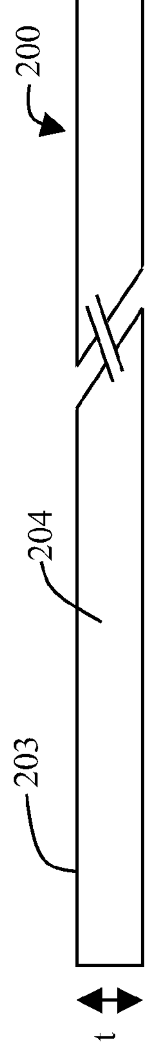


FIG. 3

FIG. 4

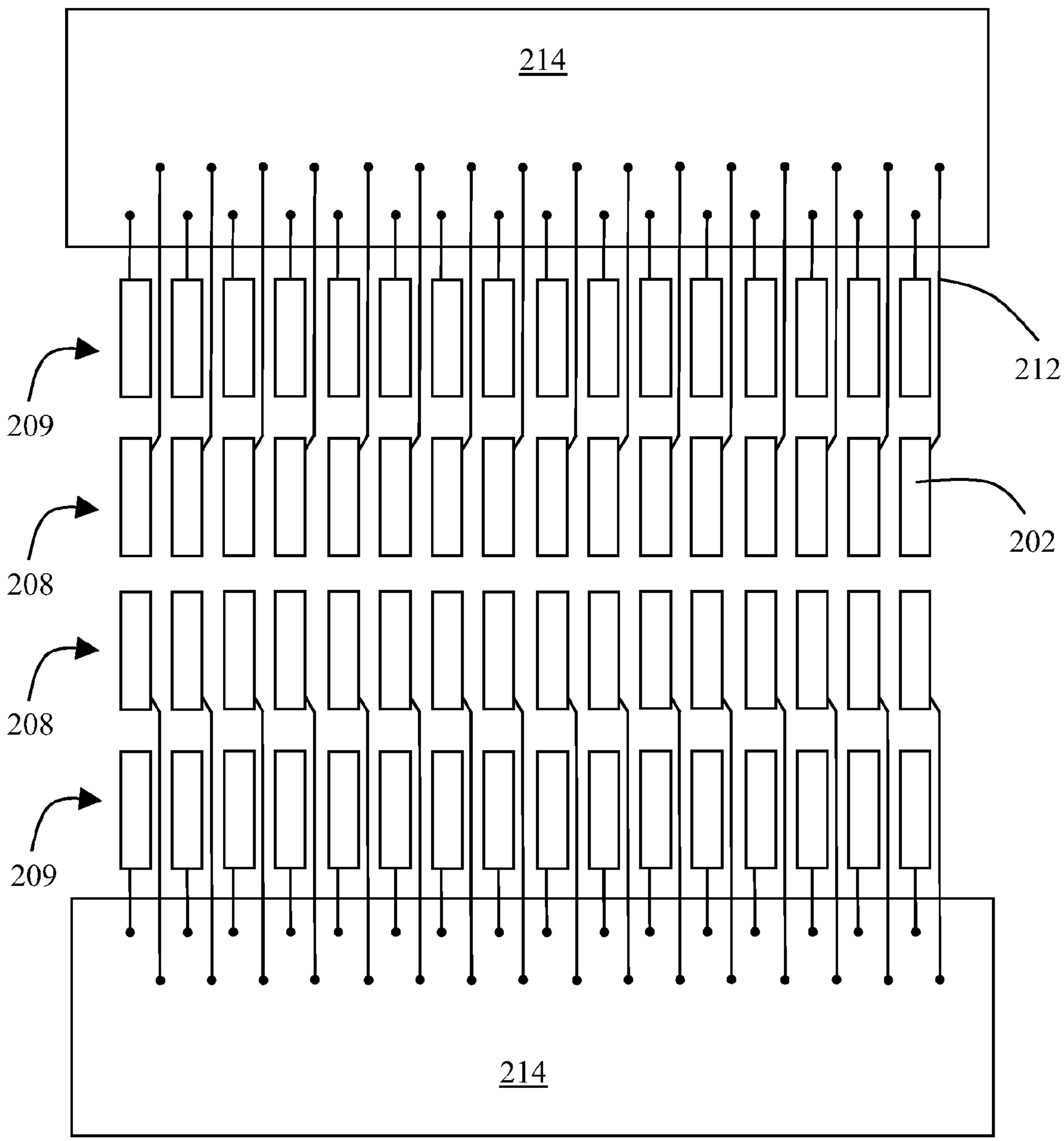
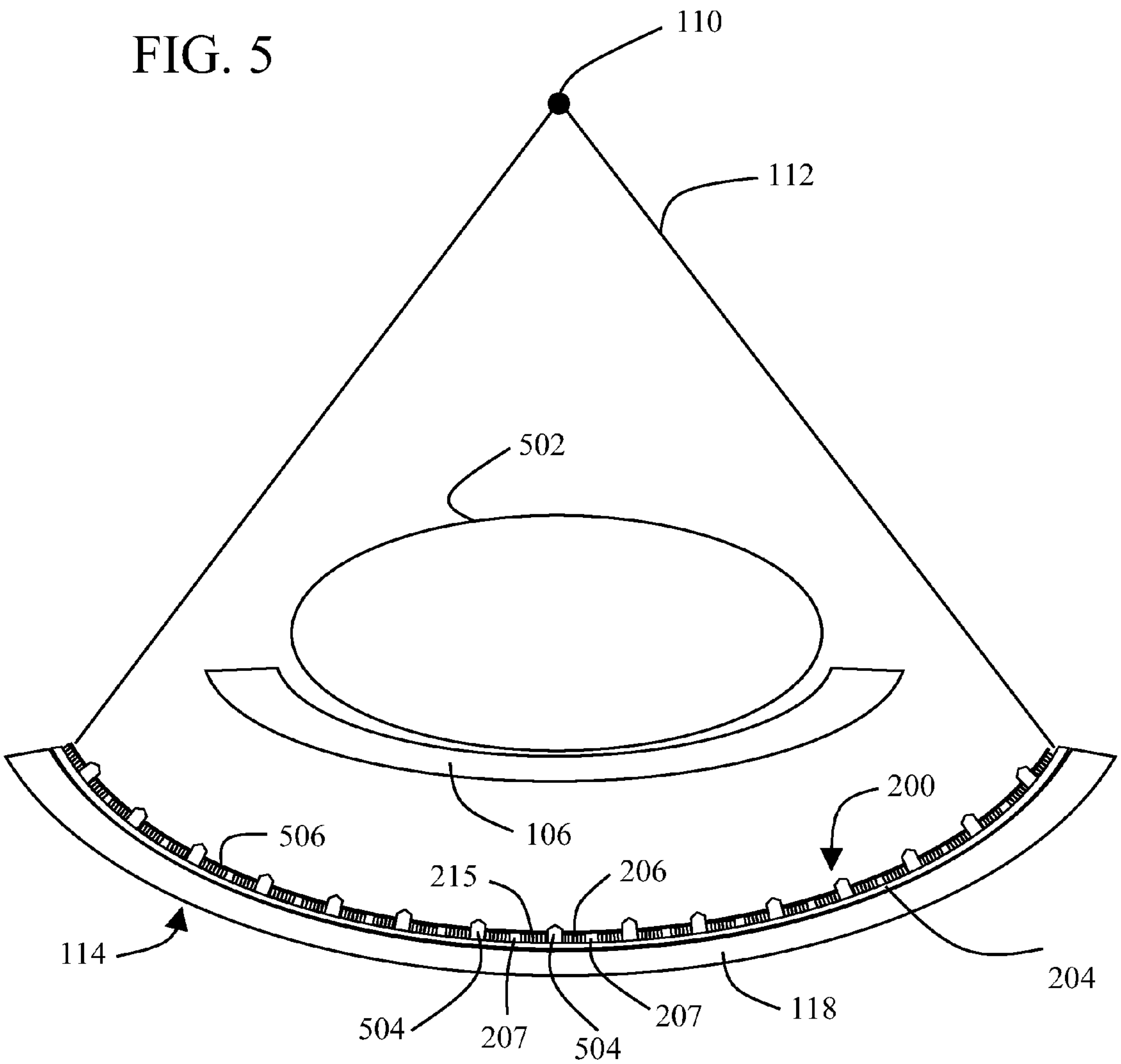


FIG. 5



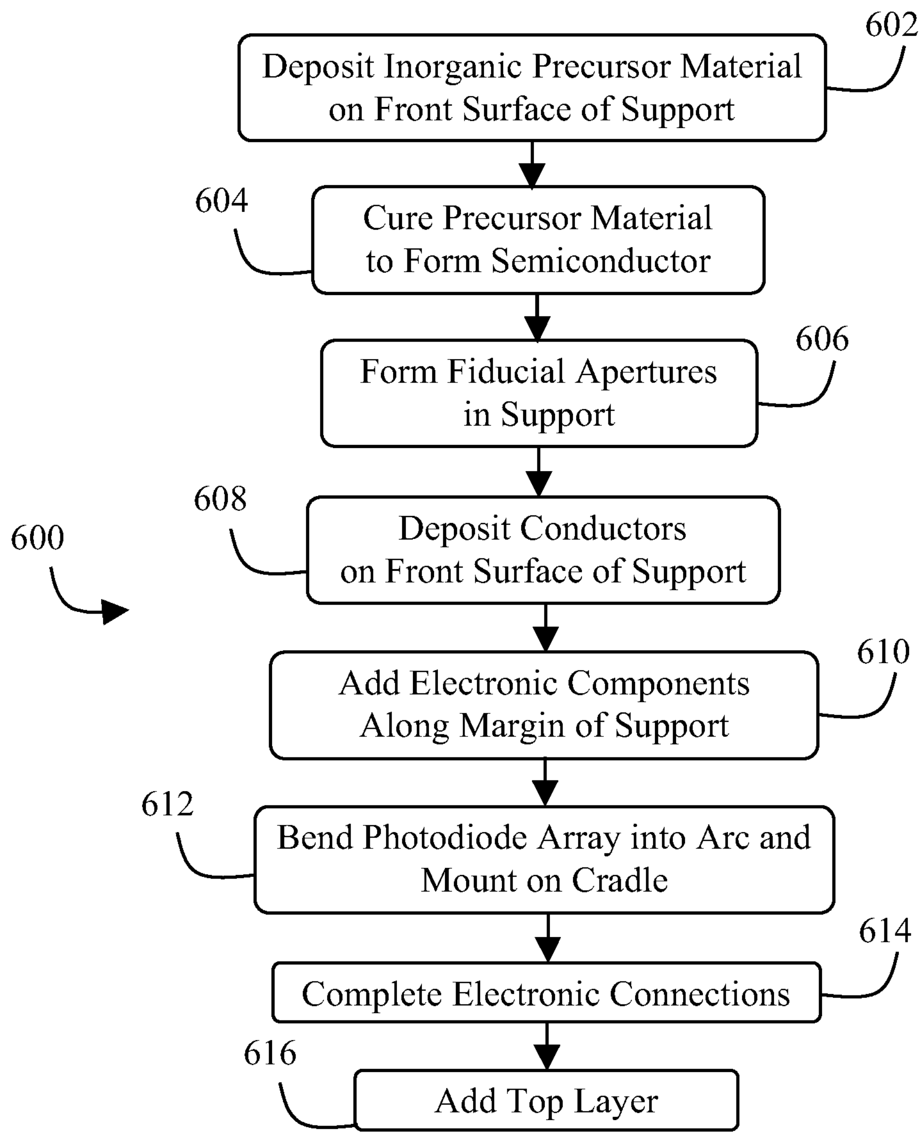

602
Deposit Inorganic Precursor Material on Front Surface of Support
604
Cure Precursor Material to Form Semiconductor
606
Form Fiducial Apertures in Support
608
Deposit Conductors on Front Surface of Support
600
610
Add Electronic Components Along Margin of Support
612
Bend Photodiode Array into Arc and Mount on Cradle
614
Complete Electronic Connections
616
Add Top Layer

FIG. 6

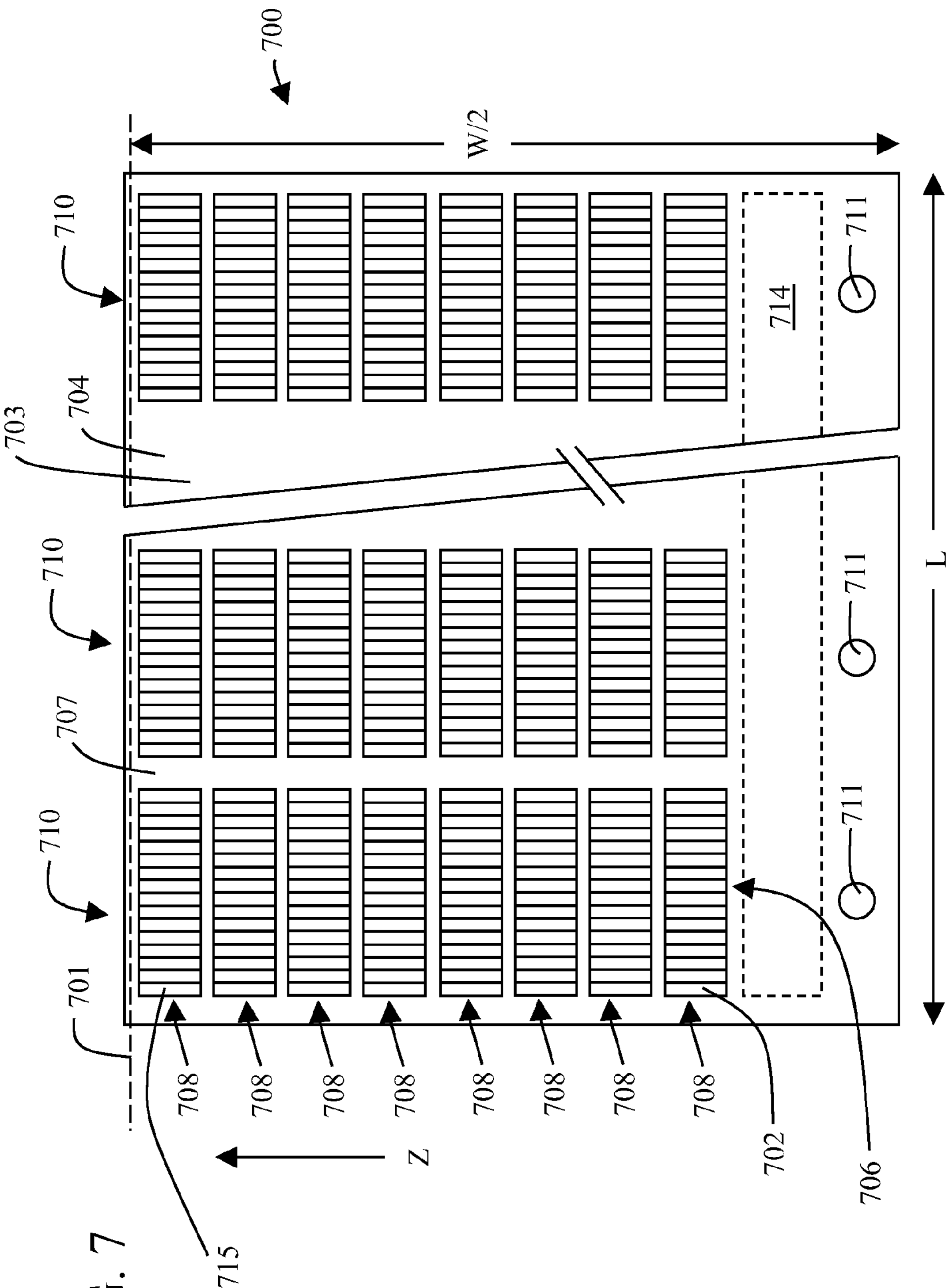

700
W/2
710
711
714
704
703
L
710
711
707
710
711
701
708
708
708
708
708
708
708
708
702
706
Z
715

FIG. 7

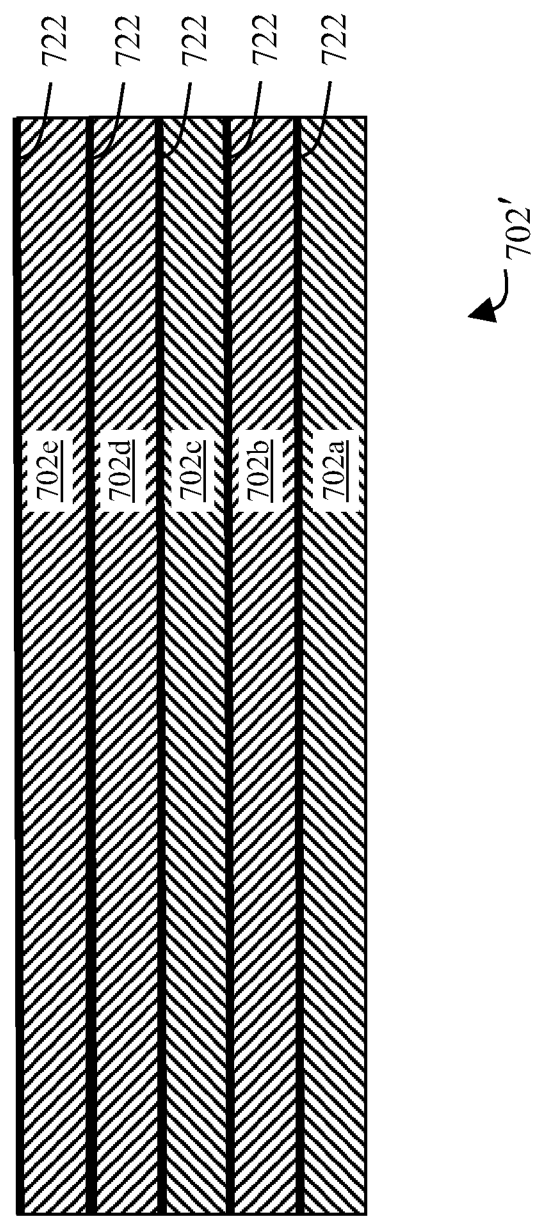


FIG. 7A

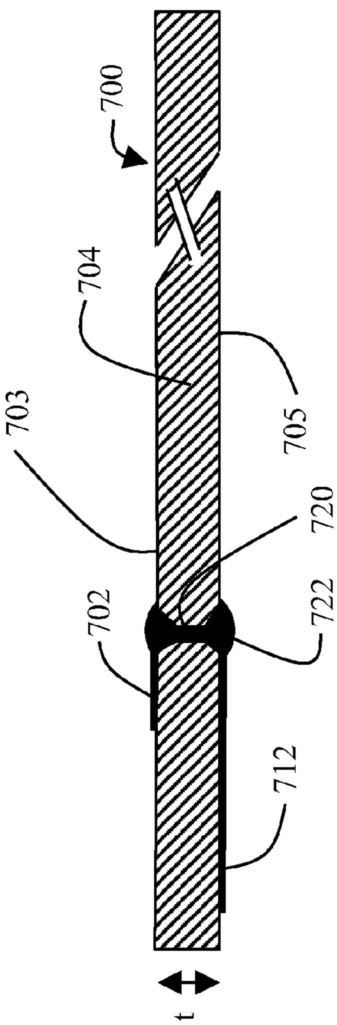


FIG. 8

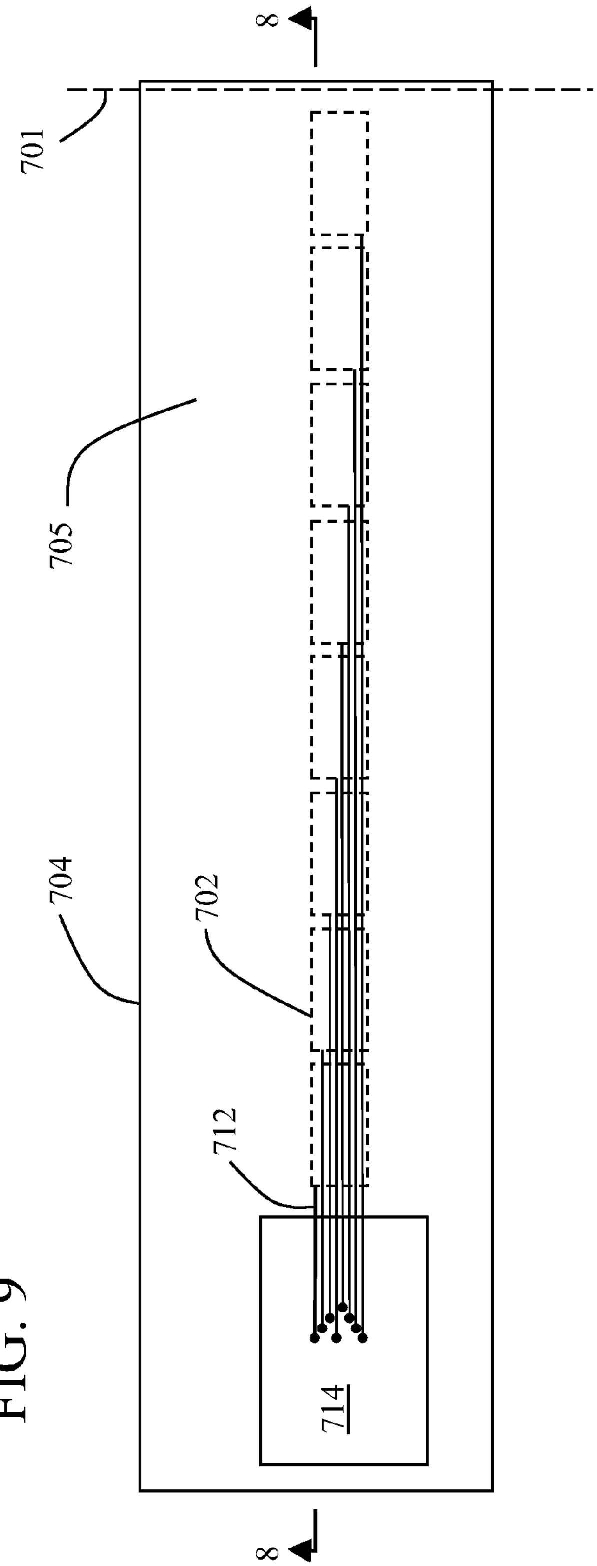


FIG. 9

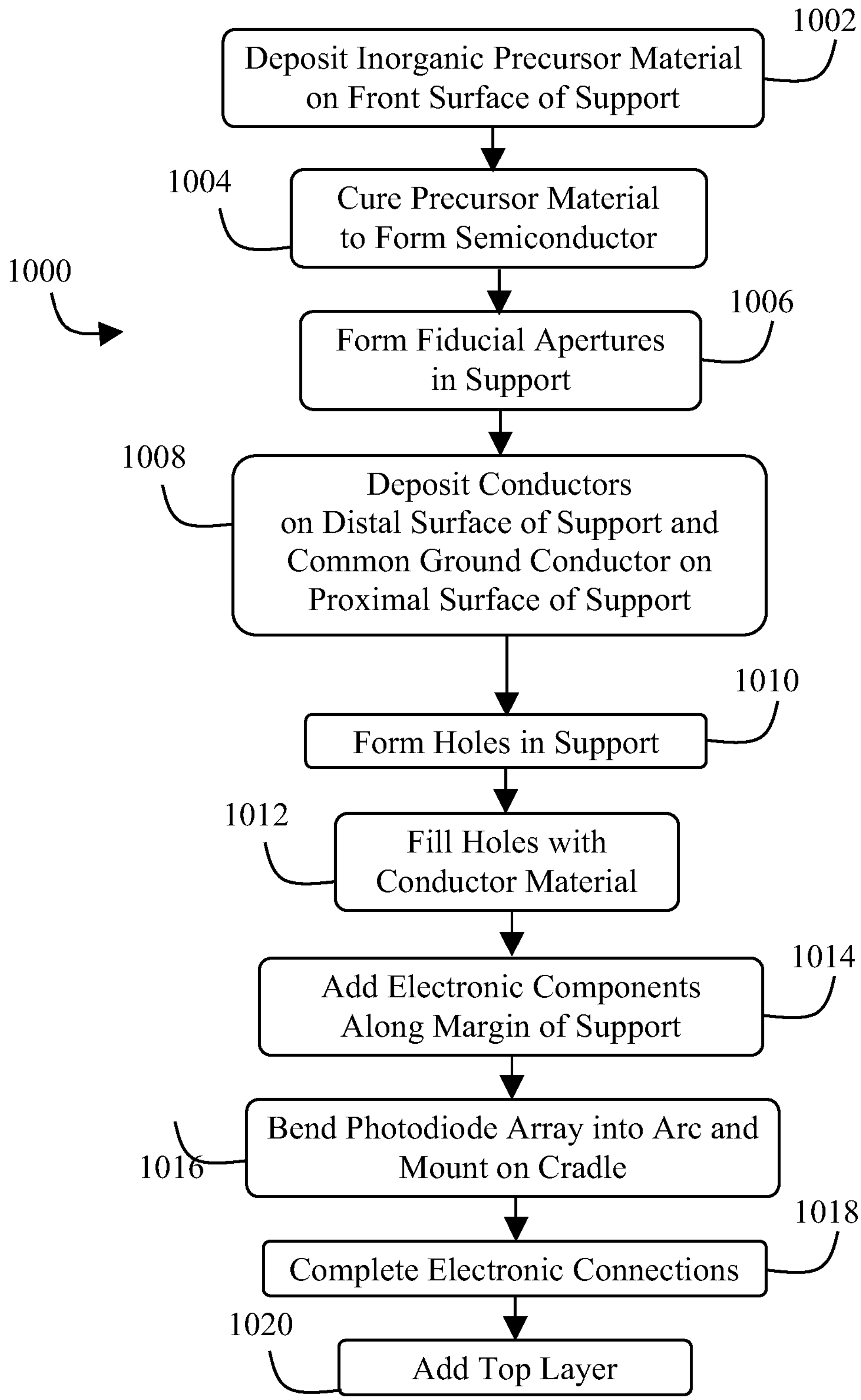

1000
Deposit Inorganic Precursor Material on Front Surface of Support
1002
Cure Precursor Material to Form Semiconductor
1004
Form Fiducial Apertures in Support
1006
Deposit Conductors on Distal Surface of Support and Common Ground Conductor on Proximal Surface of Support
1008
Form Holes in Support
1010
Fill Holes with Conductor Material
1012
Add Electronic Components Along Margin of Support
1014
Bend Photodiode Array into Arc and Mount on Cradle
1016
Complete Electronic Connections
1018
Add Top Layer
1020

FIG. 10

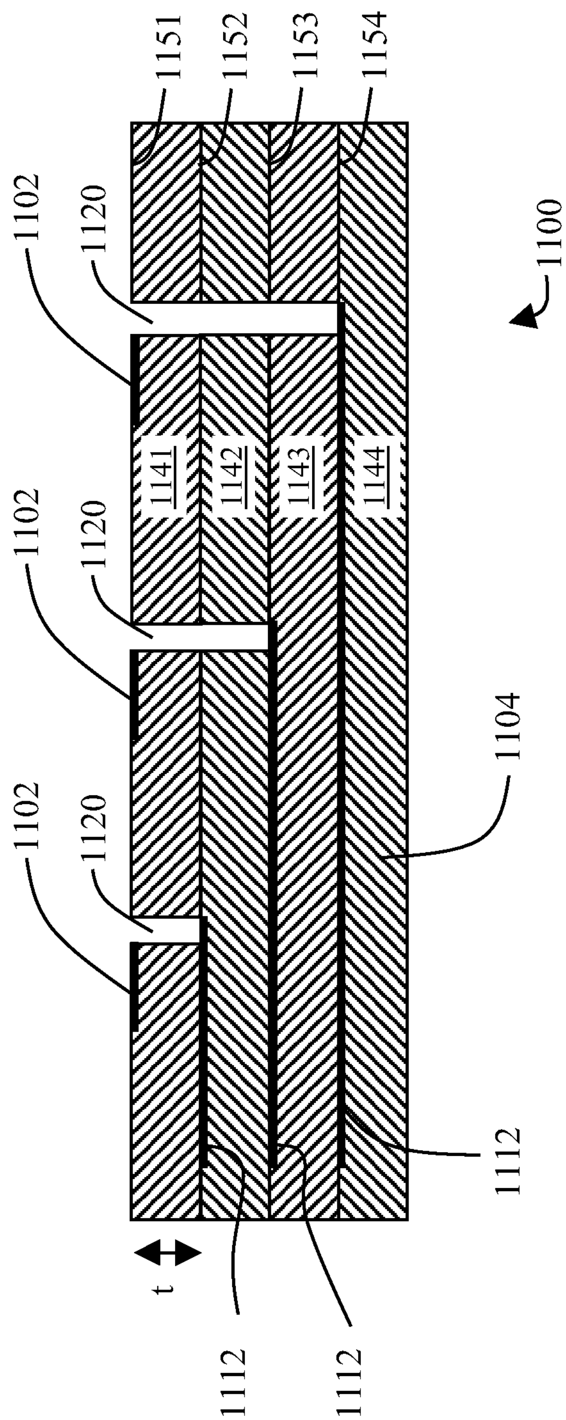

1151
1152
1153
1154
1102
1120
1100
1141
1142
1143
1144
1102
1120
1104
1102
1120
1112
t
1112
1112

FIG. 11

FIG. 12

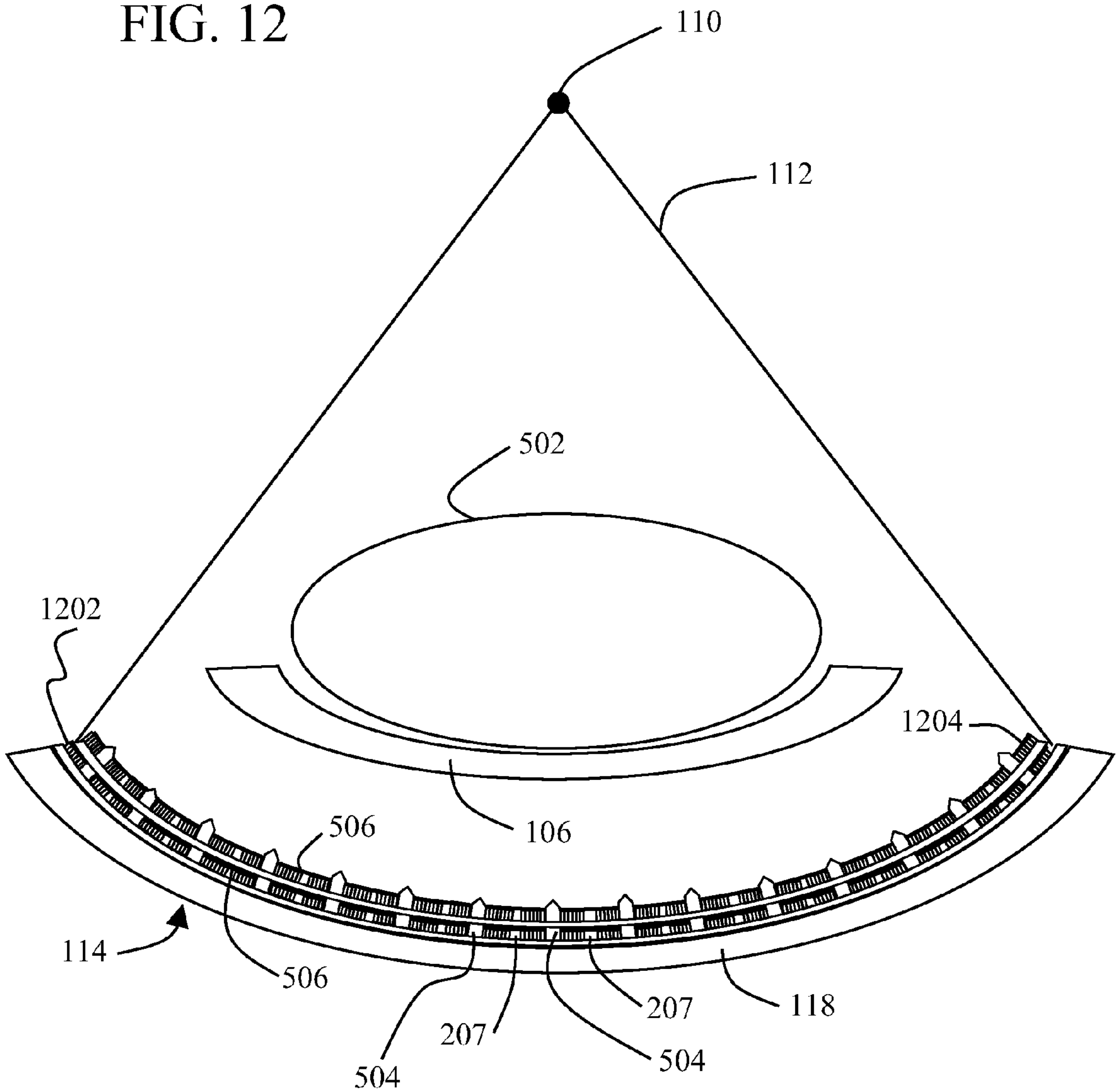


FIG. 13

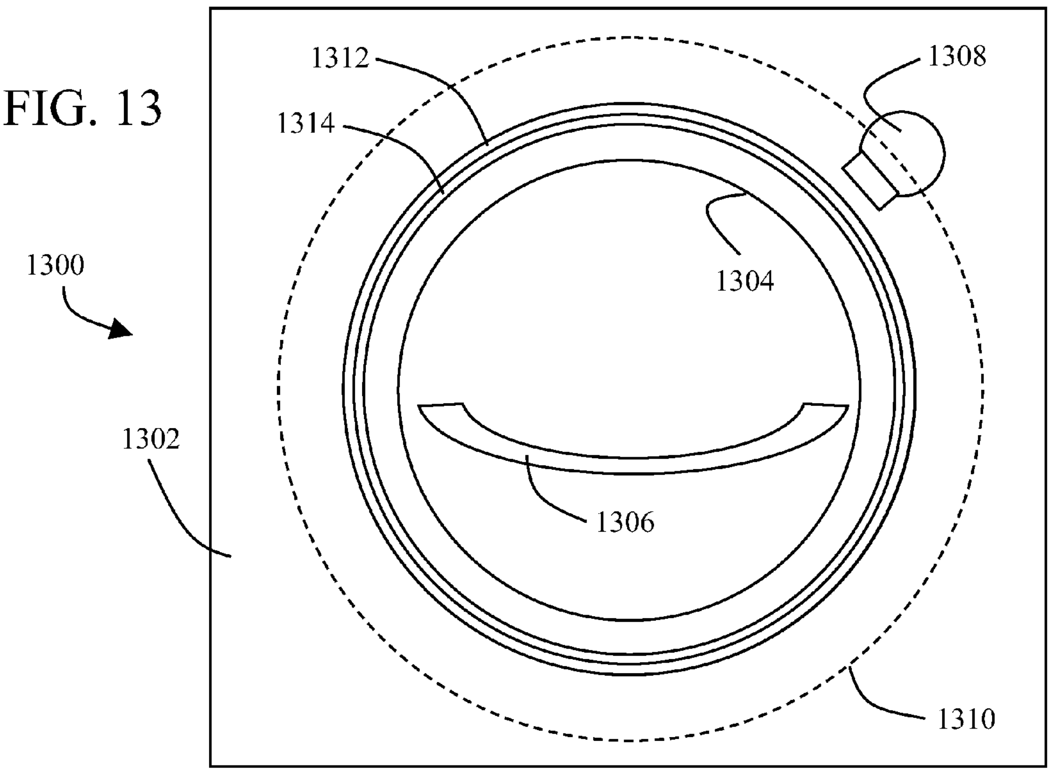
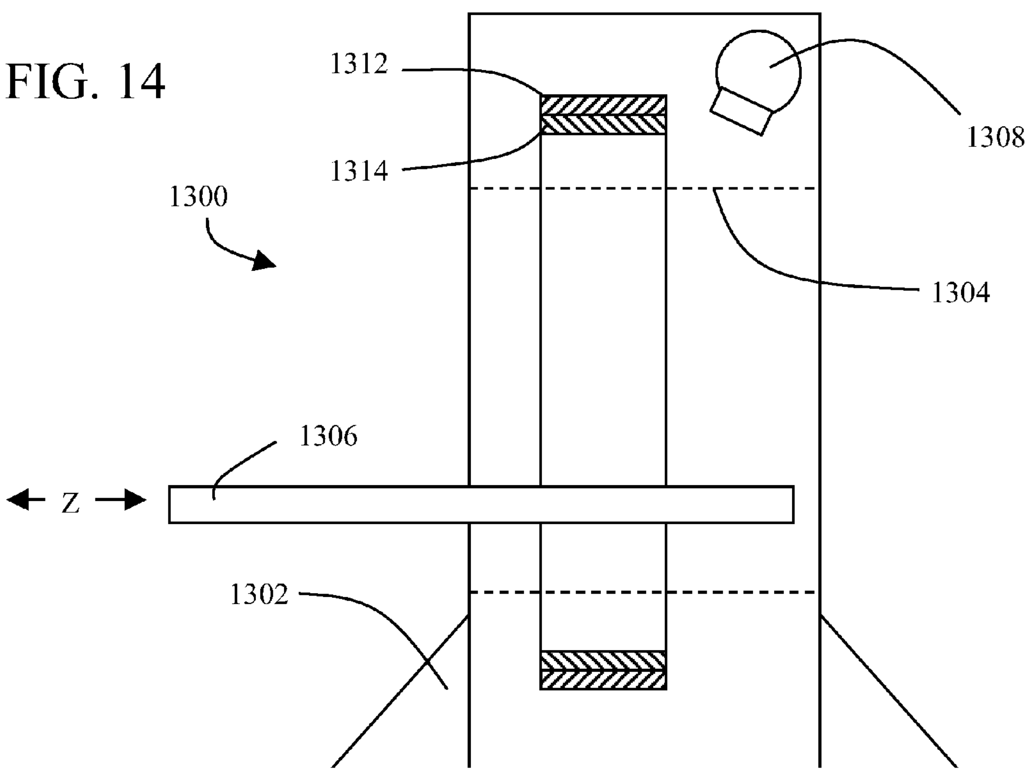

1312
1314
1308
1304
1300
1302
1306
1310

FIG. 14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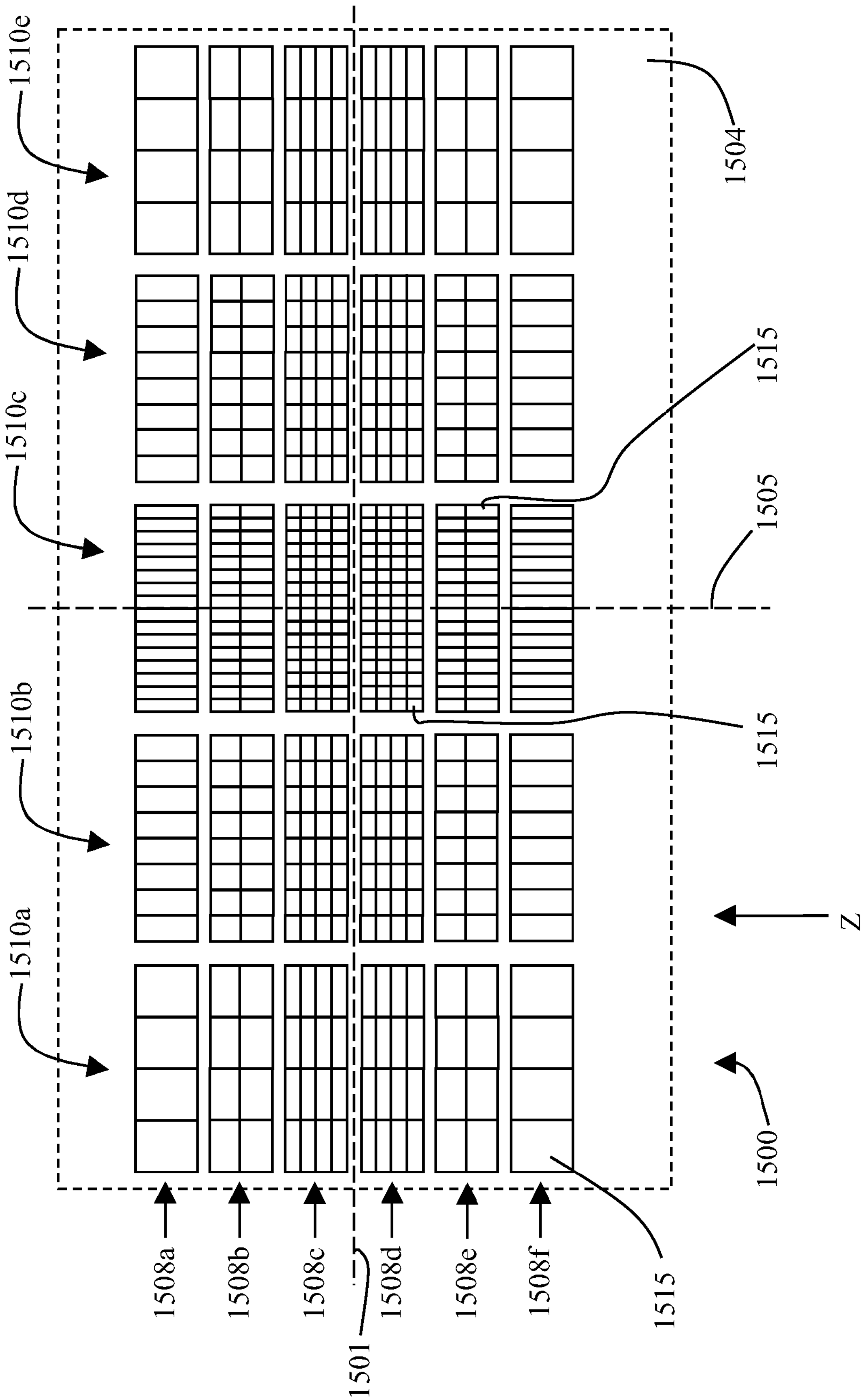
1314
1308
1300
1304
1306
Z
1302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1510b
1510c
1510d
1510e
1504
1515
1505
1515
Z
1500
1508a
1508b
1508c
1508d
1508e
1508f
1501
1515

FIG. 15

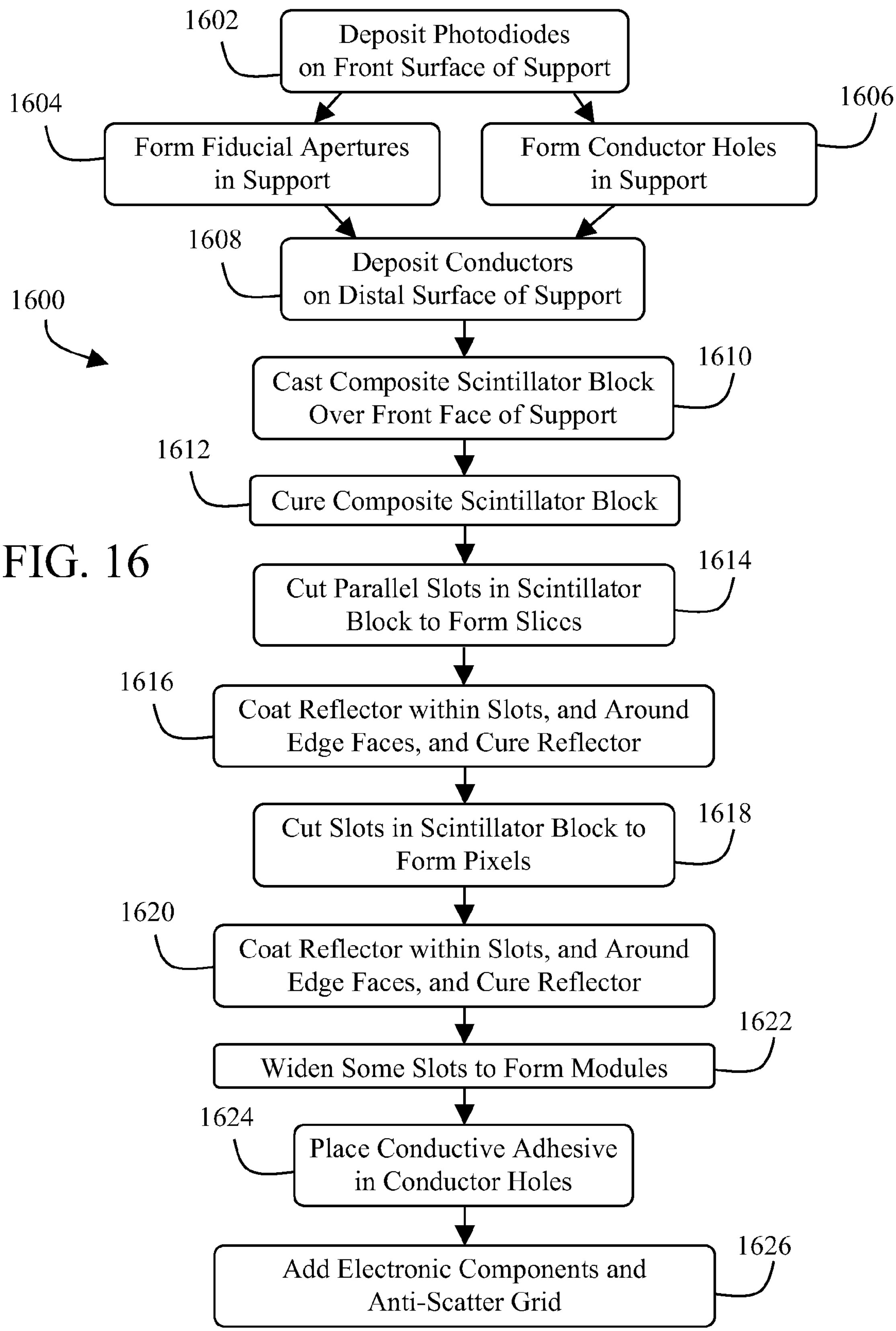

1600
1602
Deposit Photodiodes on Front Surface of Support
1604
Form Fiducial Apertures in Support
1606
Form Conductor Holes in Support
1608
Deposit Conductors on Distal Surface of Support
1610
Cast Composite Scintillator Block Over Front Face of Support
1612
Cure Composite Scintillator Block
1614
Cut Parallel Slots in Scintillator Block to Form Slices
1616
Coat Reflector within Slots, and Around Edge Faces, and Cure Reflector
1618
Cut Slots in Scintillator Block to Form Pixels
1620
Coat Reflector within Slots, and Around Edge Faces, and Cure Reflector
1622
Widen Some Slots to Form Modules
1624
Place Conductive Adhesive in Conductor Holes
1626
Add Electronic Components and Anti-Scatter Grid

FIG. 16

FIG. 17

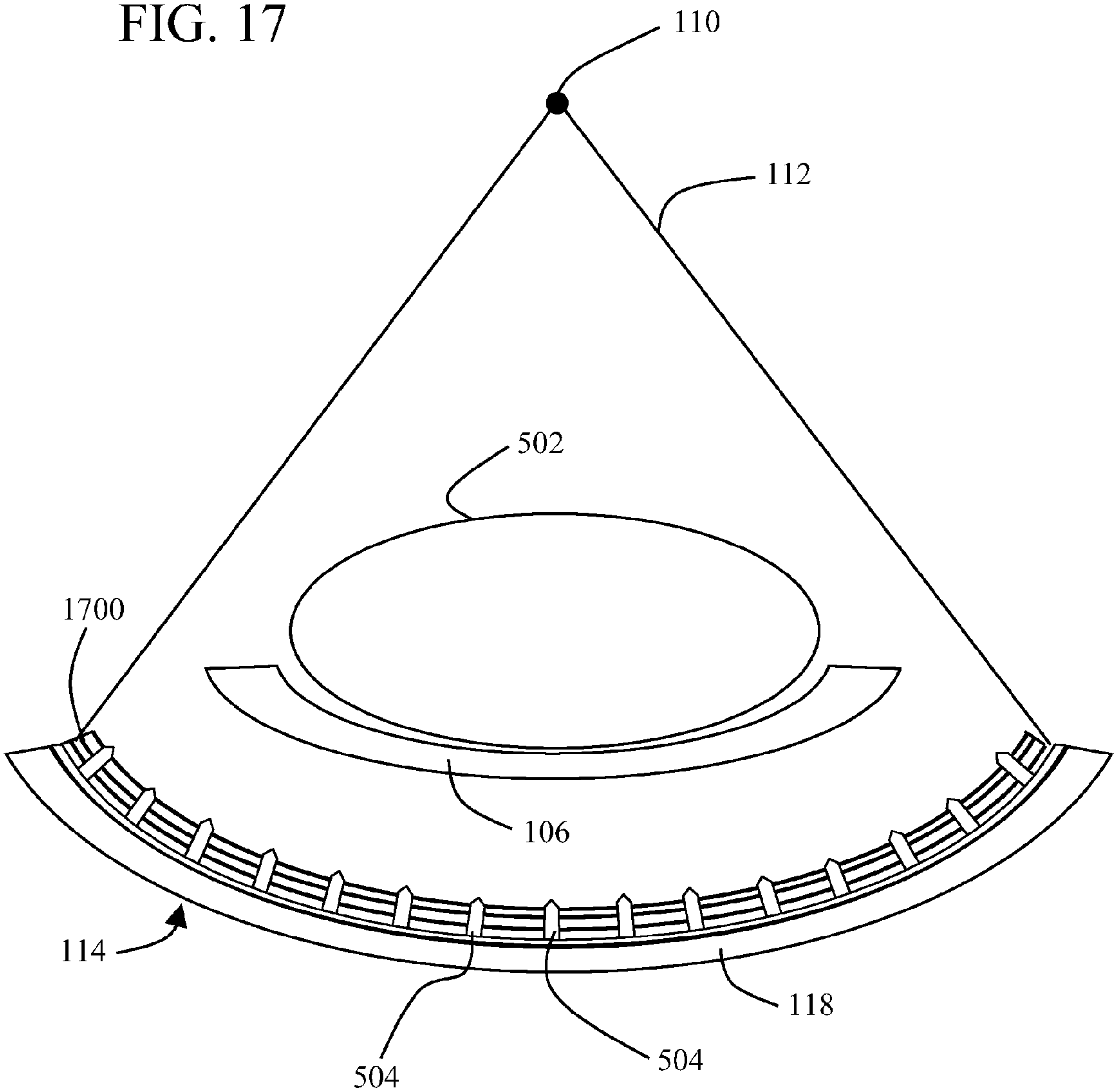


FIG. 18

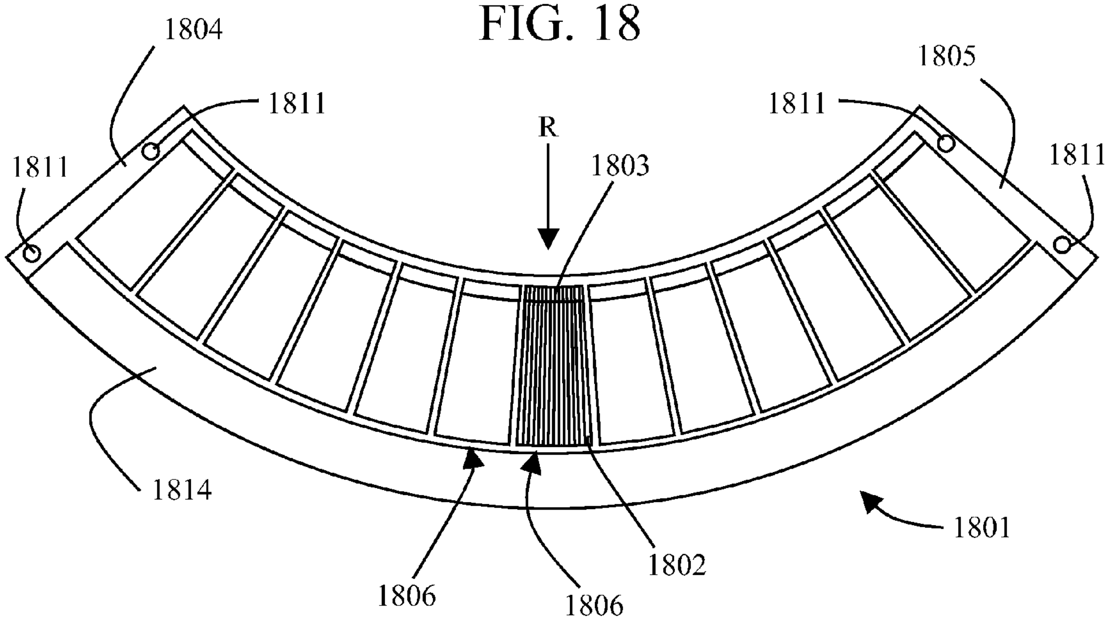

1804
1811
R
1803
1811
1805
1811
1811
1814
1801
1806
1806
1802

FIG. 19

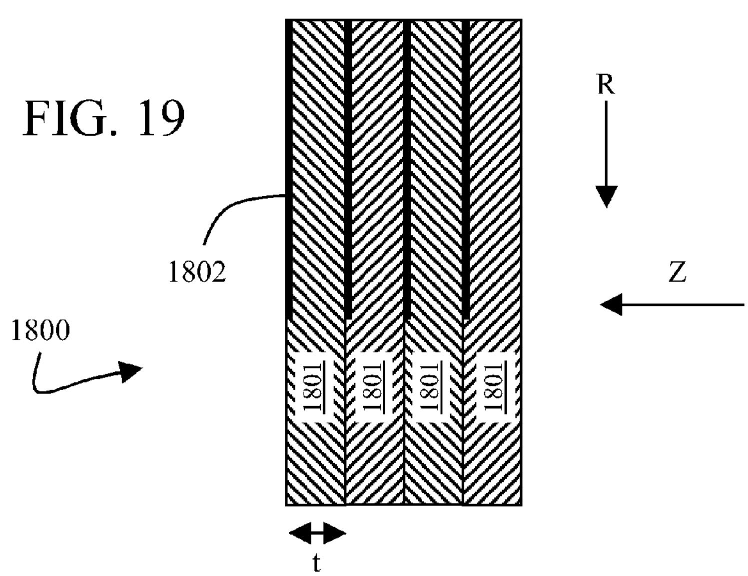

R
1802
Z
1800
1801
1801
1801
1801
t

FIG. 20

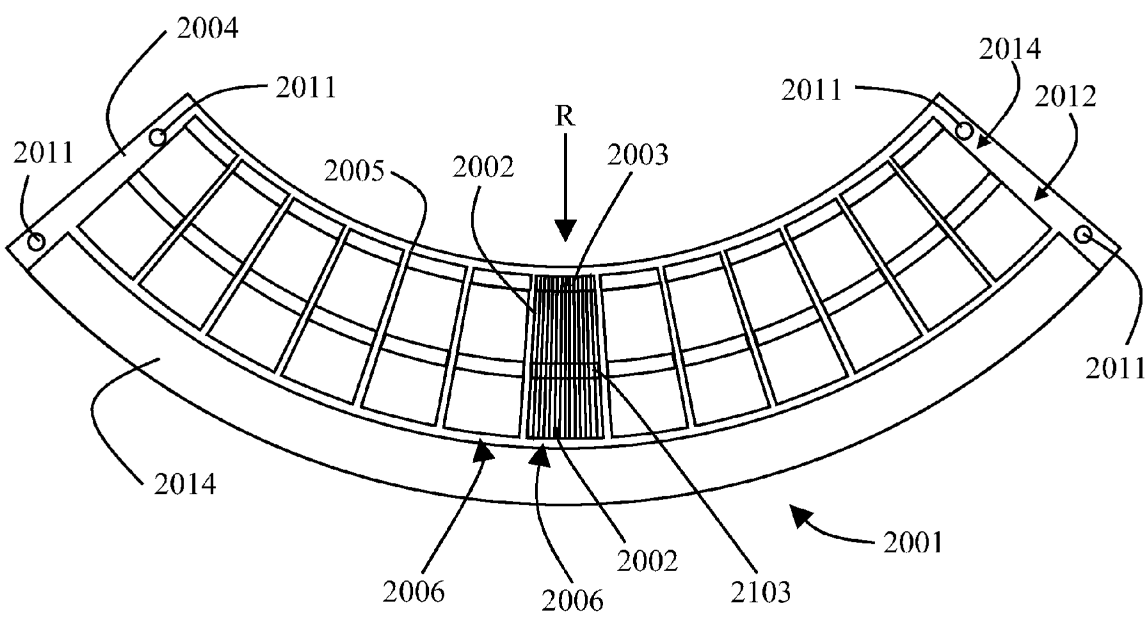

2004
2011
2011
2005
2002
R
2003
2011
2014
2012
2011
2014
2006
2006
2002
2103
2001

FIG. 21

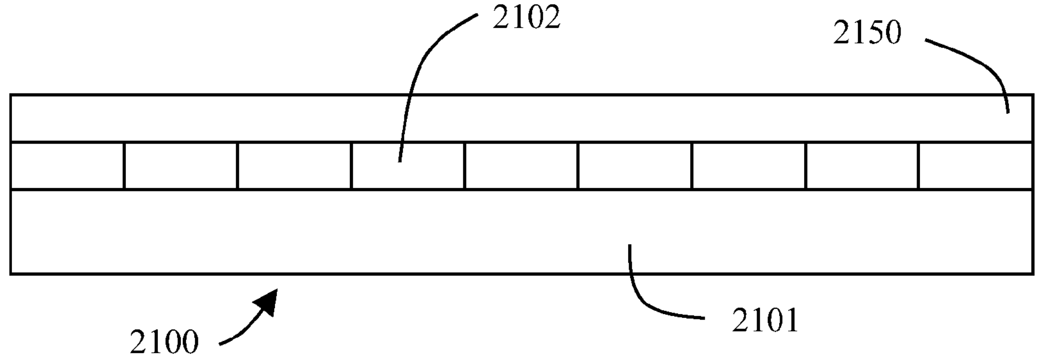


FIG. 22

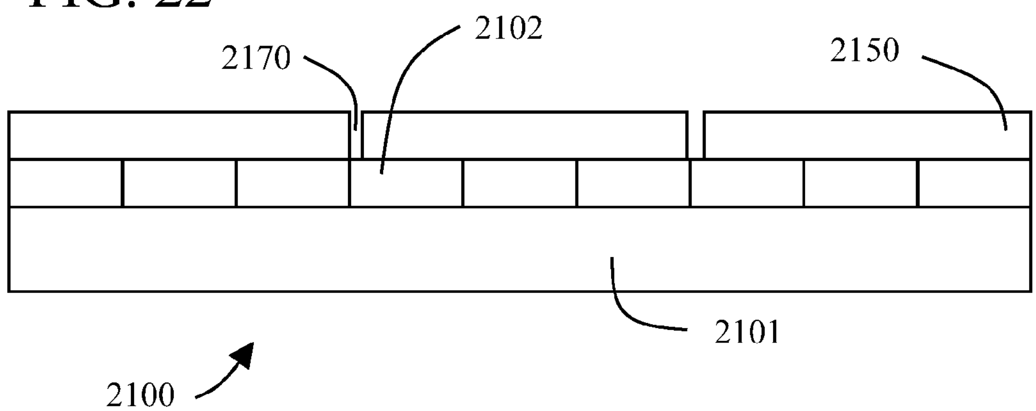
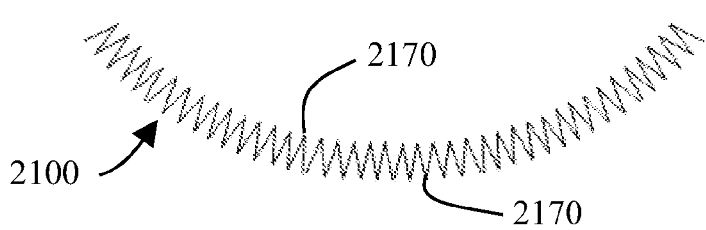


FIG. 23



IMAGING MEASUREMENT SYSTEM WITH A PRINTED PHOTODETECTOR ARRAY

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. provisional application Ser. No. 61/240,443 filed Sep. 8, 2009, which is incorporated herein by reference.

The present application relates generally to the imaging arts, and in particular a data measurement system useful for CT and other imaging modalities. These imaging modalities are useful in many contexts, such as medical imaging, security imaging for example baggage scanning, and other contexts.

One challenge posed by previously known CT imaging systems is connecting, both mechanically and electrically, the x-ray detectors to the rest of the system. Indeed, a substantial part of the cost of known CT data measurement systems arises from the connectors which enable each detector array to be plugged in to the data measurement system and be mechanically mounted upon it with high spatial and electrical precision. Good image quality in CT imaging usually requires that the dixels (detector pixels) in each array be mounted precisely with reference to each other, to the x-ray tube focal spot, and to the cradle. In addition, previously known CT imaging systems include large numbers of precision components to form scintillator assemblies, which are also costly to make and assemble into the overall system.

The present invention achieves the requisite precision at a low cost by using large area x-ray photodetector arrays. In a first embodiment, the x-ray photodetectors comprise an inorganic direct photoelectric conversion material formed in a single thick layer of material. In a second embodiment, the x-ray photodetectors comprise a lamination of several thin layers of an inorganic photoelectric conversion material, the combined thickness of which is large enough to absorb incoming x-rays with a high detector quantum efficiency. In a third embodiment, the x-ray photodetectors comprise a lamination of several layers of inorganic or organic photodiodes, wherein each layer has a composite scintillator coating thin enough that the coating's self-absorption and scattering does not materially reduce the light output of the scintillator coating, despite a potentially large difference in refractive index between the scintillator powder and the resin in which it is dispersed to form the composite.

These designs substantially reduce the cost and complexity of the overall data measurement system. The proposed systems also lend themselves to duplication in layers to form a multi-layer spectral CT data measurement system such as a two layer spectral CT system. Thus, large area photodetector arrays forming a data measurement system in a CT or other imaging apparatus are very beneficial. The present invention further concerns various structures and geometries for using large area photodetector arrays in a CT scanner or other imaging scanner data measurement system.

According to one aspect of the present invention, an imaging system is provided including a radiation source which rotates around a central z-axis of the imaging system to perform imaging scans, and a printed inorganic x-ray photodetector array including several discrete photodetectors printed in rows and columns on a support that is curved, such that each row of photodetectors is aligned along the curve of the curved support, and each column of photodetectors is aligned in parallel to the central z-axis of the imaging system. The inorganic x-ray photodetectors may comprise for example CIGS, $AuInGaSe_2$, or $AuInThSe_2$. Each photodetector forms one of the dixels of a detector array. The detector array may include two or more layers, each comprising a printed inorganic x-ray photodetector array, for use as a spectral CT imaging system.

According to another aspect of the present invention, a bendable printed inorganic x-ray photodetector array assembly for use in an imaging system is provided, including a bendable support. The bendable support may be, for example, a PET sheet, a polyimide sheet, a PEET sheet, or a nylon sheet. The array assembly is mountable within a cradle, such that each photodetector forms a dixel, as an image data measurement system in an imaging apparatus. The detector array may include two or more layers for use as a spectral CT imaging system. Related methods of making such arrays are also provided.

In a third embodiment, the x-ray photodetectors comprise a lamination of several layers of inorganic or organic photodiodes, wherein each layer has a composite scintillator coating thin enough that the coating's self-absorption and scattering does not materially reduce the light output of the scintillator coating, despite a potentially large difference in refractive index between the scintillator powder and the resin in which it is dispersed to form the composite.

Numerous advantages and benefits will become apparent to those of ordinary skill in the art upon reading the following detailed description of preferred embodiments. The invention may take form in various components and arrangements of components, and in various process operations and arrangements of process operations. The drawings are only for the purpose of illustrating preferred embodiments and are not to be construed as limiting the invention.

FIG. **1** illustrates a CT imaging apparatus **100**;

FIGS. **2** and **3** are respectively a front view and a side view of an inorganic photodetector detector array **200**;

FIG. **4** is a close-up view of the front surface of the inorganic photodetector detector array **200**;

FIG. **5** is a schematic trans-axial view of the inorganic photodetector detector array **200** disposed within the CT imaging apparatus **100**;

FIG. **6** illustrates a process **600** of manufacturing and assembling the inorganic photodetector detector array **200**;

FIG. **7** is a partial front view of an inorganic photodetector detector array **700**;

FIG. 7A is a view of a laminated photodetector;

FIG. **8** is a cross-sectional side view of the inorganic photodetector detector array **700**, taken along line **8**-**8** in FIG. **9**;

FIG. **9** is a close-up view of the distal surface of the inorganic photodetector detector array **700**;

FIG. **10** illustrates a process **1000** of manufacturing and assembling the inorganic photodetector detector array **700**;

FIG. **11** is a cross-sectional view of an inorganic photodetector detector array **1100** having more than one layer;

FIG. **12** is a schematic transaxial view of a spectral CT imaging system;

FIGS. **13** and **14** are respectively a schematic front view and a schematic sectional side view of a fourth generation CT imaging apparatus **1300**;

FIG. **15** schematically shows a photodetector array **1500** having dixels of varying sizes;

FIG. **16** illustrates a process **1600** of manufacturing and assembling an inorganic photodetector detector array, using a composite scintillator;

FIG. **17** is a schematic transaxial view of a CT imaging system incorporating a detector measurement system having laminated photodetector arrays with composite scintillators;

FIG. **18** is a schematic trans-axial view of a sectorial-shaped imaging element **1801** using an inorganic photodetector array with composite scintillators;

FIG. **19** is a schematic cross-sectional side view of an inorganic detector array **1900** incorporating several sectorial-shaped elements **1801**;

FIG. **20** is a schematic trans-axial view of a sectorial-shaped imaging element **2000** using an inorganic photodetector array appropriate for a spectral CT apparatus; and

FIGS. **21** through **23** shows an array **2100** of photodetectors suitable for use to be tilted at an angle to the x-ray beam.

CT IMAGING APPARATUS

FIG. **1** illustrates one example of a CT imaging apparatus **100** for performing an imaging scan. A CT imaging acquisition system **102** includes a gantry **104** and a table **106** which moves along the z-axis. A patient or other object to be imaged (not shown) lies down on the table **106** and is moved to be disposed within an aperture **108** in the gantry **104**. Once the patient or object is in position, an x-ray source **110** emits a projection of x-rays **112** to be gathered by an x-ray data measurement system **114** inside the gantry **104**. (A portion **116** of the gantry **104** is cut away in FIG. **1** to show the x-ray source **110** and x-ray data measurement system **114** which are housed inside the gantry **104**.) The data measurement system **114** includes several photodetectors (not shown) disposed on a cradle **118**. The x-ray source **110** and data measurement system **114** rotate together around the aperture **108** to record CT imaging data from various positions, often in conjunction with linear movement of the table **106**. This rotation is possible because the x-ray source **110** and the cradle **118** are each mounted to a common rotor (not shown) inside the gantry **104**.

The CT imaging acquisition system **102** then passes the CT imaging data on to a CT imaging, processing and display system **120** through a communication link **101**. Although the systems **102** and **120** are shown and described here as being separate systems for purposes of illustration, they may in other embodiments be part of a single system. The CT imaging data passes to an image processor **122** which stores the data in a memory **124**. The image processor **122** electronically processes the CT imaging data to generate images of the imaged patient or other object. The image processor **122** can show the resulting images on an associated display **126**. A user input **128** such as a keyboard and/or mouse device may be provided for a user to control the processor **122**.

CT Data Measurement Systems (Four Slices)

As shown in FIGS. **2** and **3**, one data measurement system described herein includes an inorganic photodetector detector array **200** which may be a printed inorganic photodetector array. The array **200** is composed of several, preferably inorganic photodetectors **202** printed on the front surface **203** of a support **204**, each of which forms an imaging dixel **215** of the array **200**. The inorganic photodetectors **202** as shown in FIG. **2** are rectangular in shape, although any shape may be used, and the size of the photodetectors is preferably on the order of approximately 0.5 to 5 mm by 0.5 to 5 mm, and most preferably approximately 1 mm by 1 mm. The inorganic photodetectors **202** may be arranged in groups **206** of photodetectors **202**, with for example sixteen photodetectors **202** in each group **206**. There may be a gap **207** between each adjacent group **206** of photodetectors **202**, in order to facilitate proper alignment of the photodetectors **202** in a curved configuration as described below. Although not shown in FIGS. **2** and **3**, there may be a gap in between any two adjacent photodetectors **202** in a given group **206**, resulting in a pitch in each direction of approximately 1.2 mm. The groups **206** are arranged in for example four rows **208** and forty-two columns **210**, although only three columns **210** are shown in FIG. **2**, for a total of 2,688 photodetectors **202** in the array **200**. Thus the inorganic photodetector detector array **200** will typically be approximately 75 to 100 cm in length L, approximately 15 cm in width W, and approximately 100 μm in thickness t. Such an array **200** is useful for a four slice CT imaging system, wherein each of the four rows **208** represents an imaging slice. Thus, the array **200** is disposed within a CT imaging apparatus **100** so that the z-axis is oriented as shown in FIG. **2**. This arrangement of inorganic photodetectors **202** in an array **200** is merely representative; any other arrangement may be used as well to suit the needs of a particular application.

The support **204** of the inorganic photodetector array **200** is preferably a stable yet bendable plastic sheet. The support **204** may be, for example, a polyethylene terephthalate (PET) sheet, a polyimide sheet, a polyaryletheretherketone (PEEK) sheet, or a nylon sheet. Several fiducial apertures **211** are placed along each side of the support **204**.

The inorganic photodetectors **202** may be deposited on the support **204**, for example, by a printing process. As an exemplary embodiment, U.S. Patent Application Publication No. 2007/0163639 to Robinson et al. discloses a method and device for fabricating photovoltaic cells incorporating inorganic semiconductor films based on Group 11 (old style IB), Group 13 (old style IIIA) and/or Group 16 (old style VIA) compounds, and is incorporated herein by reference for that disclosure. In summary, the Robinson '639 method begins with a dispersion material which includes at least one element from Group 11, 13 and/or 16. Among other advantages, use of Group 16 or chalcogenic compounds results in a low melting point, which is an advantage over more traditional Si-based dispersion materials. However, in connection with the present invention, the dispersion material may use any element from Groups 11, 13 and/or 16. In one preferred embodiment, CIGS (copper indium gallium di-selenide) is used to form the dispersion material. In another preferred embodiment, a gold-based semi-conductor such as $AuInGaSe_2$ or $AuInThSe_2$ could be used, for example.

According to the Robinson '639 method, the dispersion material is coated on to a substrate to form a precursor layer, for example by a high throughput roll-to-roll printing process. The resulting precursor layer is in turn cured to form a thin but dense semiconductor film. The curing step may be accelerated by heating the precursor layer to a temperature greater than an annealing temperature of the precursor layer, but less than a melting temperature of the substrate. Use of a substrate of very high melting point such as PEEK enables hotter curing. The cured film is then used to form a semiconductor absorber for a photodetector device. For the direct detection of x-rays contemplated herein, the semi-conductor photodetector geometry and material composition should be chosen to optimize charge collection efficiency, with the electrodes at the peripheral surfaces of the semi-conductor diode, to maximize collection of the charge developed by conversion of the incoming x-rays for collection with a minimum of time delay.

The Robinson '639 printing method is but one example of an appropriate printing method; other suitable printing processes may be used as well. For a four slice array such as the array **200**, such processes include other kinds of roll-to-roll printing, silk-screen printing, and spin coating printing of the inorganic photodetectors **202** at low resolution on the support **204**. An ink jet printing process may also be employed to deposit the inorganic photodetectors **202** on the support **204**, when higher definition is required, for example for smaller dixels.

The inorganic photodetectors **202** of the exemplary array **200** are direct detectors; that is, they directly harness incoming x-rays and produce an electrical signal indicative of the incoming x-rays. In alterative embodiments, the photodetectors may be indirect detectors; in those embodiments, scintillator elements are disposed on top of the photodetectors to convert incoming x-rays to another form of light, and that second form of light is then harnessed by the photodetectors to indirectly produce an electrical signal indicative of the incoming x-rays.

As shown in FIG. **4**, electrical conductors **212** on the front surface **203** of the support **204** lead from each inorganic photodetector **202** to a side of the array **200**. FIG. **2** does not show the conductors **212** for the sake of clarity in that Figure. The conductors **212** for the inorganic photodetectors **202** in the two inner rows **208** may pass between two adjacent photodetectors **202** in the two outer rows **209**. The conductors **212** connect the inorganic photodetectors **202** to "active" electronic components **214** mounted at each side of the array **200**, such as for example amplifiers, analog-to-digital convertors, multiplexers, application-specific integrated circuits (ASICs), and the like, together with output connectors. The active electronic components **214** may be formed in approximately 5 cm wide margins along the sides. In this way, the conductors **212** may carry power to, and also carry output signals from, each inorganic photodetector **202**. In addition, one electrode of each inorganic photodetector **202** is also connected to a ground, which may be a common ground, such as through a transparent conducting layer disposed above the photodetectors **202**.

In an alternative embodiment, the photodetectors **202** may be formed by several stacked layers. In such embodiments, each layer of the photodetector **202** is first separately formed by disposing an inorganic material which is preferably at least about 100 μm thick on a support, and then curing it to form a semiconductor layer. The semiconductor layers are then stacked and laminated to form a semiconductor thick enough to efficiently absorb the x-radiation. This the CIGS layers are preferably stacked to a total thickness of approximately 3.5 mm. The thick semiconductor is then disposed on a base support, wherein the base support contains the electrical conductors **212** and "active" electronic components **214** to process the signal from the thick stacked semiconductor.

As shown in FIG. **5**, once the inorganic photodetector array **200** has been assembled to form dixels **215**, it may be inserted into a cradle **118** for use as a data measurement system **114** in a CT imaging apparatus such as the apparatus **100** described above. Thus, FIG. **5** schematically illustrates the inter-relationships between the x-ray source **110** which produces the x-ray projections **112**, the patient or object **502** to be imaged lying on a table **106**, and the inorganic photodetector array **200**. The cradle **118** may include fiducial pins **504**, which extend through the fiducial apertures **211** in the support **204** of the array **200** in order to properly align the array **200** within the cradle **118** and, therefore, within the entire apparatus **100**. The pins **504** may additionally be used to properly align one or more anti-scatter grids (not shown) above the array **200**. The array **200** may additionally or solely be held in place on the cradle **118** with a suitable adhesive. The array **200** and cradle **118** together make up a data measurement system **114**. The size of the dixels **215**, in relation to the size of the other components in the apparatus, has been greatly exaggerated in FIG. **5** for purposes of illustration. As already mentioned, in an actual data measurement system **114**, there might be approximately forty-two groups **206** of dixels **215** spanning the arc length of the data measurement system **114** instead of the fifteen groups **206** shown in the Figure. A layer **506** of plastic, such as polytetrafluoroethylene (PTFE) loaded with TiO_2, may be placed over the inside surface of the arc of the array **200**. This layer **506** adds strength to the array **200**.

An inorganic photodetector detector array **200** may be manufactured, and assembled within a data measurement system, according to the process **600** illustrated in FIG. **6**. The ordering of the steps of the process **600** as shown in FIG. **6** may be changed to suit the needs of a particular application, and some steps may be added or removed from the exemplary process **600** shown and described here.

The inorganic precursor material is first deposited **602** on a front surface **203** of the support **204** in a photodetector **202** array **200**. This deposition may be achieved, for example, by a printing process whereby the inorganic material making up the photodetectors **202** is printed on to the support **204**, as already described. Depending on the size and application of the photodetector array **200**, suitable printing processes might include roll-to-roll printing, silk-screen printing, spin coating printing, and ink jet printing. The inorganic material may also be deposited from solution and photo-etched to form patterns.

The array **200** is then heated and cured **604** to form a thin but dense film of semiconductor.

Fiducial apertures **211** are formed **606** in the support **204**.

Electrical conductors **212** are deposited **608** on the front surface **203** of the support **204**, with one conductor **212** leading from each inorganic photodetector **202** to a side of the array **200**. The conductors **212**, like the photodetectors **202** themselves, may be added with a printing process applied to the front surface **203** of the support **204** where the photodetectors **202** are located. Similarly, one electrode of each inorganic photodetector **202** is connected in common to ground, such as through a transparent conducting layer disposed above the photodetectors **202**. Associated "active" electronic components **214** are added **610** at each side of the array **200**, such as for example amplifiers, analog-to-digital convertors, multiplexers, application-specific integrated circuits (ASICs), and the like, together with output connectors.

The inorganic photodetector array **200** is bent **612** into an arc, to conform to the radius of a rigid cradle **118** centered on an x-ray source **110**. The bent array **200** is mounted **612** to the cradle, such as with fiducial pins **504**, and/or adhesive, or any other means to achieve the precise positioning required to properly focus the photodetectors **202** on the x-ray source **110**.

The electronic connections are completed **614**, and any further electronic components required to complete the assembly of the data measurement system are added. A layer **506** of white plastic, such as polytetrafluoroethylene (PTFE), may be added **616** over the inside surface of the arc of the array **200**. This layer **506** adds strength to the array **200**.

CT Data Measurement Systems (More than Four Slices)

The inorganic photodetector array **200** discussed above is suitable for a four slice CT imaging apparatus. Making such an array **200** for larger CT imaging systems, such as sixteen to sixty-four slices or one hundred twenty-eight slices, can be difficult. Enough room must be found on the front surface **203** of the array support **204** for both the photodetectors **202** and the conductors **212**, without excessively reducing the active areas of the photodetectors **202** and reducing their sensitivity. To overcome such difficulties, an alternative inorganic photodetector detector array **700** is shown in FIGS. **7** and **8** which is more suitable to imaging systems with more than four slices. More particularly, half of such an array **700** on one side of a centerline **701** is shown in the Figures. The two halves of the array **700**, one shown in the Figures and the other not shown, are symmetrical about the centerline **701**.

Thus the array **700** is composed of several inorganic photodetectors **702** disposed on the front surface **703** of a support **704**, each of which forms an imaging dixel **715** of the array **700**. The inorganic photodetectors **702** as shown in FIG. **7** are rectangular in shape, although any other shapes such as hexagonal shapes may advantageously be used, and the size of the photodetectors is preferably on the order of approximately 0.5 to 5 mm by 0.5 to 5 mm, and most preferably approximately 1 mm by 1 mm. The inorganic photodetectors **702** may be arranged in groups **706** of photodetectors **702**, with for example sixteen photodetectors **702** in each group **706**. There may be a gap **707** between each adjacent group **706** of photodetectors **702**, in order to facilitate proper alignment of the photodetectors **702** in a curved configuration as described below. The groups **706** are arranged in for example sixteen rows **708** and forty-two columns **710**, although only three columns **710** are shown in FIG. **7**. Thus the inorganic photodetector detector array **700** will typically be approximately 75 to 100 cm in length L, approximately 20 to 30 cm in width W, and approximately 100 μm in thickness t. Such an array **700** is useful for a sixteen slice CT imaging system, wherein each of the sixteen rows **708** represents an imaging slice. Thus, the array **700** is disposed within a CT imaging apparatus **100** so that the z-axis is oriented as shown in FIG. **7**. This arrangement of inorganic photodetectors **702** in an array **700** is merely representative; any other arrangement may be used as well to suit the needs of a particular application.

Each photodetector **702** is composed of an inorganic material, as already discussed above in connection with the photodetectors **202** of the array **200**. The inorganic photodetectors **702** may be deposited on the support **704**, for example, by a printing process. Suitable printing processes include roll-to-roll printing, silk-screen printing, and spin coating printing of the inorganic photodetectors **702** at low resolution on the support **704**. An ink jet printing process may also be employed to deposit the inorganic photodetectors **702** on the support **704**. The inorganic material may also be deposited from solution and photo-etched to form patterns.

Also as in the array **200**, the support **704** of the inorganic photodetector detector array **700** is preferably a stable yet bendable plastic sheet. The support **704** may be, for example, a polyethylene terephthalate (PET) sheet, a polyimide sheet, a polyaryletheretherketone (PEEK) sheet, or a nylon sheet. It likewise has fiducial apertures **711**. However, unlike the array **200**, the conductors **712** of the array **700** are not located on the front surface **703** of the support **704**.

Rather, as schematically illustrated in FIGS. **8** and **9**, the conductors **712** are located on the distal surface **705** of the support **704** opposite the front surface **703**, and are connected to respective photodetectors **702** through holes **720** in the support **704**. This construction is advantageous due to space limitations on the front surface **703** of the support **704**, resulting from the number of photodetectors **702** located thereon. Because the distal surface **705** of the support **704** is free of any photodetectors **702**, there is much more space available in which to place the conductors **712** than on the front surface **703**.

The holes **720** may be made in the support **704** using the focussed beam of a continuous wave or a pulsed laser such as a 10.6 μm carbon dioxide (CO_2) laser or a 1.06 μm Nd-YAG laser. If a CW laser is used it is preferable to use nitrogen blanketing. The conductor **712** coating the relevant regions of the distal surface **705** of the support **704** is preferably a bright metal or other good reflector of the laser beam, and arrests its further penetration. After the holes **720** are formed, they can be filled with micro-drops of conductive adhesive **722** from the front surface **703** to complete the connection to the conductor **712** on the distal surface **705**. Preferably, a flexible resin is employed to permit bending at a later stage without damage.

The conductors **712** may be formed on the distal surface **705** of the support **704** (which may be a non-absorbing glossy plastic) using conventional ink jet printing technology. A representative example of such technology is disclosed in U.S. Pat. No. 5,933,168, incorporated herein by reference for its disclosure of ink jet printing technology, which states droplets of 5 to 7 nanograms were produced. To adapt the teachings of that patent, or other conventional ink jet printing technology, it is desirable to choose a material for the photodetector **702** material and/or the conductor **712** and **722** material which matches the fluidic parameters of the ink fluid used. Ideally, these include the ratio of density to volume compressibility, kinematic viscosity, contact angle, and surface tension. It may be useful to select a rubber diaphragm resistant to the materials being printed. It is believed that ink jet printing is able to achieve a space between adjacent parallel conductors **712** of down to approximately 16 μm, which corresponds to a 32 μm pitch and a density of more than 30 conductors per millimeter.

In this way, as suggested in FIGS. **8** and **9**, separate and densely spaced electrical conductors **712** lead from each inorganic photodetector **702** to a side of the array **700**. The conductors **712** thus connect the inorganic photodetectors **702** to "active" electronic components **714** mounted at each side of the array **700**, such as for example amplifiers, analog-to-digital convertors, multiplexers, application-specific integrated circuits (ASICs), and the like, together with output connectors. The electronic components **714** may be formed in approximately 5 cm wide margins along the sides, and may appear on either the front surface **703** or the distal surface **705** of the support **704**. In this way, the conductors **712** may carry power to, and also carry output signals from, each inorganic photodetector **702**. Also, one electrode of each inorganic photodetector **702** is connected to a common ground, such as through a transparent conducting layer disposed above the photodetectors **702**.

The inorganic photodetectors **702** of the exemplary array **700** are direct detectors; that is, they directly harness incoming x-rays and produce an electrical signal indicative of the incoming x-rays. In alterative embodiments, the photodetectors may be indirect detectors; in those embodiments, scintillator elements are disposed on top of the photodetectors to convert incoming x-rays to another form of light, and that second form of light is then harnessed by the photodetectors to indirectly produce an electrical signal indicative of the incoming x-rays.

In an alternative embodiment shown in FIG. 7A, the photodetectors **702** may be formed by several stacked layers, such as five layers **702***a* through **702***e* shown in FIG. 7A. In such embodiments, each layer of the laminated photodetector **702'** is first separately formed by disposing an inorganic material which is preferably at least about 100 μm thick on a support, and then curing it to form a semiconductor layer. The semiconductor layers **702***a* through **702***e* are then stacked and laminated to form a thick semiconductor photodetector array **702'**. In this laminated stack **702'**, the direct conversion photodetector layers **702***a* through **702***e* lie exactly against each other with no intervening elements.

The thick semiconductor array **702'** is next disposed on a base support, such as the support **704**, with each direct conversion photodetector layer **702***a* through **702***e* connected in parallel to the corresponding layer underneath it by a common adhesive bond **722**. In this way the conductive adhesive **722** links the stacked photodetector array **702'** to form a single dixel. Each dixel is connected by electrical conductors **712** to "active" electronic components **714** to process the signal from the thick stacked semiconductor **702'**.

Once the inorganic photodetector detector array **700** has been assembled, it may be inserted into a cradle **118** for use as a data measurement system **114** in a CT imaging apparatus such as the apparatus **100** described above. This process is substantially as shown and described above in connection with the inorganic photodetector detector array **200**, including use of fiducial pins **504**.

An inorganic photodetector detector array **700** may be manufactured and assembled within a data measurement system according to the process **1000** illustrated in FIG. **10**. The ordering of the steps of the process **1000** as shown in FIG. **10** may be changed to suit the needs of a particular application, and some steps may be added or removed from the exemplary process **1000** shown and described here.

The inorganic precursor material is first deposited **1002** on a front surface **703** of the support **704** in a photodetector **702** array **700**. This deposition may be achieved, for example, by a printing process whereby the inorganic material making up the photodetectors **702** is printed on to the support **704**, as already described. Depending on the size and application of the photodetector array **700**, suitable printing processes might include roll-to-roll printing, silk-screen printing, spin coating printing, and ink jet printing. The inorganic material may also be deposited from solution and photo-etched to form patterns.

The array **700** is then heated and cured **1004** to form a thin but dense film of semiconductor.

Fiducial apertures **211** are formed **1006** in the support **204**.

Electrical conductors **712** are deposited **1008** on the distal surface **705** of the support **704**, with one conductor **712** leading from each inorganic photodetector **702** to a side of the array **700**. The conductors **712**, like the photodetectors **702** themselves, may be added with a printing process. Holes **720** are formed **1010** in the support **704**, and filled **1012** with a conductor such as a flexible conductive epoxy resin **722** to connect each inorganic photodetector **702** to an associated conductor **712**. One electrode of each inorganic photodetector **702** is connected to a common ground, such as through a conducting layer disposed above the photodetectors **702**. The layer may but need not be transparent, and it may be cast or printed, with perforations to prevent short-circuiting the conductors of the other electrodes which pass through it. Associated "active" electronic components **714** are added **1014** at each side of the inorganic photodetector detector array **700**, such as for example amplifiers, analog-to-digital convertors, multiplexers, application-specific integrated circuits (ASICs), and the like, together with output connectors.

The inorganic photodetector detector array **700** is bent **1016** into an arc, to conform to the radius of a rigid cradle **118** centered on an x-ray source **110**. The bent array **700** is mounted **1016** to the cradle, such as with fiducial pins **504**, and/or adhesive, or any other means to achieve the precise positioning required to properly focus the photodetectors **702** on the x-ray source **110**.

The electronic connections are completed **1018**, and any further electronic components required to complete the assembly of the data measurement system are added. A layer **506** of white plastic, such as polytetrafluoroethylene (PTFE) loaded with TiO_2, may be added **1020** over the inside surface of the arc formed by the array **700**. This layer **506** adds strength to the array **700**, and forms a seal against humidity.

In this example, the inorganic photodetector array **700** is a sixteen slice array, with eight slices or rows **708** appearing on each side of the centerline **701** of the array **700**. It is believed that present printing technology has an upper pitch limit of 32 conductors per millimeter. Applying that upper limit, and assuming a photodetector **702** dixel pitch of 1 mm, the design of the array **700** may be directly applied to make an array with thirty-two slices on each side of a centerline **701**, for a total of sixty-four slices. Of course, if higher pitch printing methods are found or known, the number of available slices will correspondingly increase. Alternatively, if a lower spatial resolution of the imaging process is acceptable, the photodetector **702** dixel pitch may be reduced, providing more room in which to place the conductors **712** and so increase the number of slices.

In yet another embodiment, illustrated in FIG. **11**, a method is provided to increase the number of imaging slices to be made with a photodetector array **1100**. In this embodiment, the support **1104** has multiple layers. Four layers **1141**, **1142**, **1143** and **1144** are shown in FIG. **11** as a representative example. Each of the layers **1141**, **1142**, **1143** and **1144** is preferably a stable yet bendable plastic sheet, such as for example a polyethylene terephthalate (PET) sheet, a polyimide sheet, a polyaryletheretherketone (PEEK) sheet, or a nylon sheet. The thickness t of an individual layer may be approximately 10 μm to 100 μm. The inorganic photodetectors **1102** are disposed on the front surface **1151** of the top layer **1141**.

To assemble the multi-layer macro inorganic photodetector array **1100**, each layer **1141**, **1142**, **1143** and **1144** is printed with an appropriate network of conductors **1112** on its respective front surface **1151**, **1152**, **1153** or **1154**. The layers **1141**, **1142**, **1143** and **1144** are glued together with a flexible adhesive to form the support **1104**. Holes **1120** are formed in the support **1104**, providing a communication path between each conductor **1112** and a corresponding inorganic photodetector **1102** on the top surface **1151**. The holes **1120** may be made in the support **1104** using the focussed beam of a continuous wave or a pulsed laser, such as a 10.6 μm carbon dioxide (CO_2) laser or a 1.06 μm Nd-YAG laser. If a CW laser is used it is preferable to use nitrogen blanketing. The conductors **1112** are preferably a bright metal or other good reflector of the laser beam, to help protect deeper layers in the support **1104** from laser beam damage during formation of a hole **1120**. Thus a conductor **1112** forms the base of each hole **1120**. Control of the laser beam intensity and exposure time can ensure that the laser beam penetrates the multilayer support **1104** only as far as the reflective metal layer **1112** and no further. After the holes **1120** are formed, they can be filled with conductive adhesive (not shown) extending from the photodetector surface **1151** to the bottom of the hole **1120**, to complete the connection to each conductor **1112**.

Thus, by providing multiple layers of pathways, the available space in the array **1100** for the conductors **1112** is greatly increased. This allows more imaging slices to be formed in the array, without sacrificing the quality of images obtained using the array. This method may be used in conjunction with a laminated photodetector, as described above.

Spectral CT Scanners

The concepts discussed above can be readily applied to a spectral CT apparatus. For spectral CT, the data measurement system **114** combines two separate inorganic photodetector detector arrays together, as shown for example in FIG. **12** as a bottom inorganic photodetector detector array **1202** and a top inorganic photodetector detector array **1204**. The top array **1204** is preferentially responsive to the low-energy (softer) incident x-rays, which it filters out, leaving only the high energy (hard) x-rays to which the bottom array **1202** is preferentially sensitive. This improves statistics in photon energy spectrometry.

The bottom inorganic photodetector detector array **1202** may be identical to the inorganic photodetector detector array **200** (for up to a four slice spectral CT scanner), the inorganic photodetector detector array **700** (for up to a sixty-four slice spectral CT scanner), or the inorganic photodetector detector array **1100** (for a greater than sixty-four slice spectral CT scanner). However, the bottom inorganic photodetector detector array **1202** may preferably incorporate for example $AuInGaSe_2$ or $AuInThSe_2$, which are relatively dense inorganic semiconductor materials. There may be standard fiducial hole spacing for the fiducial pins **504**.

The top inorganic photodetector detector array **1204** is added in order to provide spectral CT imaging capability. There are two principal differences in the design of the top array **1204** versus the bottom array **1202**. First, the top array **1204** is a lower energy array, responding preferentially to softer x-rays, and thus including for example CIGS as an inorganic semiconductor material. Second, in comparison with the components of the bottom inorganic photodetector detector array **1202**, the photodetectors of the top inorganic photodetector detector array **1204** are printed to be slightly smaller in size, with slightly smaller separations, and with fiducial hole spacing slightly reduced. This permits the top detector array **1204** to be mounted on the bottom detector array **1202** in the cradle **118**, and yet still be focused on the x-ray source **110** at the correspondingly slightly smaller radius. It also permits the top detector array **1204** to be mounted within the data measurement system **114** using the same fiducial pins **504** as the bottom detector array **1202**, for precise positioning. Separate top layers **506** may be used with each detector array **1202** and **1204**.

Fourth Generation CT Scanners

The technology described herein may also be used in connection with fourth-generation CT scanners, such as the apparatus **1300** shown in FIGS. **13** and **14**. In a fourth generation CT imaging apparatus, the data measurement system comprises a complete ring of x-ray detectors surrounding the region of interest to be imaged. An offset rotating x-ray source emits x-rays which are received by the detectors, which remain stationary.

Thus, referring to FIGS. **13** and **14**, a fourth generation CT imaging apparatus **1300** has a fixed gantry **1302** with an aperture **1304** to receive a table **1306** which linearly moves along the z axis, in and out of the aperture **1304**. A patient or other object to be imaged by the fourth generation CT apparatus **1300** is disposed on top of the table **1306**. An offset x-ray source **1308** rotates around the region of interest, along a circular path **1310**. At least a first ring disposed within the gantry **1302** comprises an inorganic photodetector detector array **1312**, as discussed above. More particularly, the support elements **204**, **704** and **1104** of the embodiments respectively described above could have a length L equal to the inner circumference of a ring-shaped cradle (not shown) within the gantry **1302**. In that way the array **200**, **700** or **110** may be mounted on the inside circumference of the ring cradle, using adhesive and/or fiducial aperture-pin arrangements. In other words, in a fourth generation CT apparatus **1300**, the fixed ring cradle takes the place of the rotating cradle **118** of the arrays **200**, **700** and **1100** described above. The ring cradle may be in the form of an entire ring, or only segments of a complete ring.

Although not shown in FIGS. **13** and **14**, the fourth generation CT apparatus **1300** incorporates a processing and display system analogous to the system **120** already discussed in connection with the third generation CT imaging apparatus **100**.

Spectral CT capability may also be added to the fourth generation CT apparatus **1300**, by adding a second ring-shaped inorganic photodetector detector array **1314** inside the first ring-shaped inorganic photodetector detector array **1312**. Thus, in this spectral CT embodiment, the first inorganic photodetector detector array **1312** incorporates a relatively more dense semiconductor such as $AuInGaSe_2$ or $AuInThSe_2$, while the second inorganic photodetector detector array **1314** incorporates a relatively less dense semiconductor such as CIGS. Also, in comparison with the components of the first inorganic photodetector detector array **1312**, the photodetectors of the second inorganic photodetector detector array **1314** are slightly smaller in size, with slightly smaller separations, and with fiducial hole spacing slightly reduced. This permits the second inorganic photodetector detector array **1314** to be mounted within the circumference of the first inorganic photodetector detector array **1312** on the ring-shaped support. It also permits the second inorganic photodetector detector array **1314** to be mounted using the same fiducial pins as the first inorganic photodetector detector array **1312**, for precise positioning. More array layers may additionally be used.

The inorganic photodetector detector arrays as described herein are particularly well suited to a fourth generation CT imaging apparatus **1300**. The inorganic photodetector detector array are much less costly to produce and install than the ceramic scintillators and silicon photodetectors used in present CT imaging apparatuses. The electronic connectivity costs are also substantially reduced. Thus the cost savings realized in producing enough detectors to completely surround the region of interest can be substantial. Moreover, the requirements for uniformity and temporal stability in the data measurement system are much reduced in fourth generation CT, because the sensitivity, dark noise and linearity of each detector can all be calibrated immediately prior to each imaging exposure. And, only the x-ray source **1308** is required to rotate in the fourth generation CT apparatus **1300**, so the gantry mechanical costs can be reduced because a lower mechanical precision is required.

Variable Size Photodetector Dixel Geometries

The dixels **215** of the exemplary inorganic photodetector detector array **200**, the dixels **715** of the exemplary inorganic photodetector detector array **700**, and the dixels of the exemplary inorganic photodetector detector array **1100** all are shown and described as having the same rectangular shape as shown in the Figures. In at least one alternative embodiment, however, the size of the dixels may advantageously vary within the overall array **200**, **700** or **1100**, such as shown for example in FIG. **15**.

FIG. **15** illustrates an inorganic photodetector array **1500** having a first centerline **1501** which is transverse to the z-axis and a second centerline **1505** which is parallel to the z-axis. The photodetector array **1500** comprises several photodetector dixels **1515** of various sizes disposed on a support **1504**. The dixels **1515** are arranged in rows and columns. FIG. **15** illustrates only the six rows **1508**a through **1508**f and the five columns **1510**a through **1510**e which are closest to the center of the array, where the centerlines **1501** and **1505** cross. As can be seen, as the dixels **1515** get nearer to one of the centerlines **1501** or **1505** of the array **1500**, they decrease in size. This geometry presents a cost effective way to increase the spatial resolution of the detector array **1500** near its center, where objects are typically imaged such as shown for example in FIG. **5** with respect to the array **200**.

Persons of ordinary skill in the x-ray detector art will understand that patient does efficiency can be greatly improved by concentrating dose on the central rays of the x-ray beam, and employing detectors in that region with maximal resolution. Thus, the embodiment of FIG. **15** can also lead to a reduction in required x-ray exposure if the dixel **1515** geometry is coordinated with the specific characteristics of the x-ray source. Specifically, the bow tie x-ray filter (not shown in FIG. **15**) can be made much thinner at the edges of the detectors **1515** at the edges of the array **1500** are larger.

Composite Scintillators

The embodiments described above have incorporated inorganic photodetector arrays for directly converting incoming x-rays to an electronic signal. However, such inorganic photodetector arrays may also be used for indirect photoelectric conversion, as a photodiode in conjunction with an intermediate scintillator to form a photodetector. As one alternative of such an indirect conversion, composite scintillators such as described in U.S. Patent Application No. 61/087,195 (filed Aug. 8, 2008) and PCT Patent Application No. PCT/IB 2008/055276 (filed Dec. 12, 2008 and claiming priority to U.S. Patent Application No. 61/087,195 filed Dec. 21, 2007) can be used. Those applications are hereby expressly incorporated by reference herein for their disclosure of composite scintillators.

Such composite scintillators can achieve savings in cost and improved thermal stress performance. In particular, developing a commercially viable printing process for making inorganic semiconductors having the needed purity, quality, speed, linearity and uniformity for direct conversion might be fraught with difficulty. So, as one alternative, one might coat large area photodiode arrays (either organic or inorganic) with a layer of a composite scintillator to improve x-ray detection performance.

Thus FIG. **16** illustrates a process **1600** of manufacturing and assembling a data measurement system including an inorganic or organic photodiode array with composite scintillators. The ordering of the steps of the process **1600** as shown in FIG. **16** may be changed to suit the needs of a particular application, and some steps may be added or removed from the exemplary process **1600** shown and described here.

The photodiodes are deposited **1602** on the front face of a support, as described above. This deposition may be achieved, for example, by a printing process whereby the material making up the photodiodes, such as CIGS, $AuInGaSe_2$, or $AuInThSe_2$, is printed on to the support. Depending on the size and application of the photodiode array, suitable printing processes might include roll-to-roll printing either by vacuum deposition or preferably at atmospheric pressure, silk-screen printing, spin coating printing, and ink jet printing. The photodiode material may also be deposited from solution and photo-etched to form patterns. Fiducial apertures are formed **1604** in the support, and conductor holes are also formed **1606** in the support. Electrical conductors are deposited **1608** on the distal surface of the support, with one conductor leading from each photodiode to a side of the array. The conductors, like the photodiodes themselves, may be added using a printing process applied to the support. One electrode of each photodiode is connected to a common ground, such as through a transparent conducting layer disposed proximally above the photodiodes.

A thin composite scintillator block is then cast **1610** over the front face of the support, for example by dispersing scintillator powder in a suitable resin or plastic, and cured **1612**. A wide range of scintillator materials may be used, including GOS, garnets (such as GGAG), ZnSe, ZnS and ZnO powders. These scintillator materials can be inexpensively prepared by wet chemical methods with no need for crystallisation or sintering. Rare earth halides such as LuI_3, YI_3 or SrI_2, which typically give higher light outputs, may be used if care is taken to minimize the presence or formation of moisture.

If the composite scintillator is thin, then little light will be lost by scattering or self-absorption in the scintillator layer and the geometric optical efficiency will be very high. Thus, the thickness of the composite scintillator coating is preferably between approximately 100 to 250 μm. Alternatively or in addition, the powder component of the composite scintillator can be nano-particulate or be of relatively low concentration. This ensures that the self-absorption in the composite scintillator coating layer is tolerable, and that the light output is not too seriously reduced by scattering, in spite of substantial mismatch ($\delta n=0.2$) between the refractive indices of the powder and the resin in the composite. Low-index scintillators such as $LuPO_4$ or BaF_2, with a better match to the refractive index of the resin can permit thicker layers.

The composite scintillator coating may be deposited on the photodiode array in any number of ways. In a first way, a continuous film of composite scintillator material is deposited with an optical absorber or dye that absorbs light at the emission wavelength to reduce lateral cross-talk in the composite scintillator.

In a second way, the composite scintillator coating may be scribed such as mechanically or with a laser to form dixels, each juxtaposed upon a corresponding photodiode element of the array, and separated by air gaps or paint to inhibit cross-talk. Thus, a series of parallel slots are cut **1614** in the scintillator block, corresponding to borders between adjacent photodiodes underneath the scintillator block. In this way, elongated slices are formed in the scintillator block. A white reflector is coated within the slots between the slices, and on the edge faces, of the scintillator block and cured **1616**. Another series of cuts are made **1618** to the scintillator block, to form slots perpendicular to the previous cuts **1614**, so that the combined slot pattern forms dixels in combination with the photodiodes underneath the scintillator block. A white reflector is coated within the new slots, and on the edge faces, of the scintillator block and cured **1620**. If desired, some of the slots may be widened **1622** to form modules, so that the array may more easily be bent into a curved configuration.

In a third way of depositing a scintillator coating on a photodiode array to form photodetectors, individual composite scintillator elements are printed directly onto each photodiode by suitable printing processes, with black absorbing ink added in the interstices between composite scintillator elements to prevent cross-talk between them.

In a fourth way of disposing a scintillator coating on a photodiode array for form photodetectors, a commercial x-ray image-intensifying screen is employed. This is applied to the front face of the photodiode arrays using optical cement. A series of parallel slots are cut **1614** in the intensifying screen, corresponding to borders between adjacent photodiode underneath the screen, to form elongated slices as in the cast composite scintillator block.

Conductive adhesive is placed **1624** within the conductor holes of the support, in order to electrically connect the inorganic photodiodes on the front surface of the support to the conductors on the distal surface of the support. Associated "active" electronic components are mounted **1626** at each side of the array, such as for example amplifiers, analog-to-digital convertors, multiplexers, application-specific integrated circuits (ASICs), and the like, together with output connectors. An anti-scatter grid may also be added **1626** to the array. Then the data measurement system is bent into an arc and placed within a cradle, by positioning the fiducial apertures of the support over fiducial pins in the cradle to properly focus on an x-ray source. Using an appropriate geometry, this process may be used for third or fourth generation data measurement systems.

These combined composite scintillator/inorganic photodiode arrays can achieve adequate x-ray stopping power in any one of several ways. In a first embodiment, several layers of composite scintillator/inorganic photodiodes can be laminated to form a thick detector laminate, such as shown in FIG. **17**. Shown therein is a three-layer laminate **1700** of composite scintillator/inorganic photodiode arrays held together and aligned by fiducial pins **504**. In such a multi-layer laminate, commercial x-ray intensifying screens may b used to form the composite scintillator in the laminations. In a similar manner, multi-layer laminates of combined composite scintillator/photodiode array layers may be incorporated into a fourth generation CT imaging apparatus, wherein each layer is in the shape of a complete ring. Such laminates could also suitably be used in a spectral CT apparatus, by separately reading out the photodiode arrays in the integrating mode.

In a second embodiment, a detector array **1800** is made by combining together several sectorial-shaped elements **1801** in a stacked relationship, wherein each element **1801** corresponds to a single imaging slice of the array **1800**. As shown in FIG. **18**, each slice array element **1801** includes several organic or inorganic photodiodes **1802** and corresponding composite scintillators **1803** deposited on a first side **1805** of a support **1804**, perhaps in groups **1806**, to form photodetectors. For ease of illustration, the individual photodiodes **1802** and scintillators **1803** of only one group **1806** are shown in FIG. **18**. The photodiodes **1802** and composite scintillators **1803** as shown in the Figure are sectorial in shape, although any shape may be used. The cross-sectional size of the top of the composite scintillators **1803** exposed to the incoming radiation R is preferably on the order of approximately 0.5 to 5 mm. The composite scintillators are preferably on the order of approximately 0.5 to 6 mm high, to absorb all the radiation R. Thus, the array **1800** is disposed within a CT imaging apparatus **100** so that the z-axis is oriented as shown in FIG. **19**. The thickness t of each photodiode slice **1801** along the z-axis is preferably approximately 100 μm or less, so that little of the emitted optical radiation R is absorbed in the scintillators **1803**, and the geometric quantum efficiency (DQDE) is high. The base is preferably slightly thicker than the tip. In an actual slice element **1801**, approximately forty-two groups **1806** with approximately sixteen photodetectors **1802** in each group (or six-hundred and seventy-two total photodetectors **1802**) for example may span the arc length of the support **1804**, although only thirteen groups **1806** are shown in the Figure.

Each photodiode **1802** may be composed of an inorganic material, as already discussed above in connection with the other embodiments herein, or an organic material. The photodiodes **1802** may be deposited on the support **1802**, for example, by a printing process. Suitable printing processes include roll-to-roll printing such as by vacuum deposition or preferably at atmospheric pressure, silk-screen printing, and spin coating printing of the photodiodes **1802** at low resolution on the support **1804**. For higher spatial resolution, an ink jet printing process may also be employed to deposit the photodetectors **1802** on the support **1804**. The material may also be deposited from solution and photo-etched to form patterns.

The support **1804** of the system **1800** is preferably a stable, thin rigid plastic sheet. The support **1804** may be, for example, a polyethylene terephthalate (PET) sheet, a polyimide sheet, a polyaryletheretherketone (PEEK) sheet, or a nylon sheet. The sheet may be for example between about 9 and 30 μm thick. An additional thin metallic support (not shown) may be added to provide further strength and rigidity. The support **1804** likewise has fiducial apertures **1811**, like those in other embodiments.

Electrical conductors (not shown in the Figures) lead from each photodiode **1802** to "active" electronic components **1814** mounted on the support **1804**. Such components may include for example amplifiers, analog-to-digital convertors, multiplexers, application-specific integrated circuits (ASICs), and the like, together with output connectors. The conductors may be formed using conventional ink jet printing technology or roll-to-roll printing. The conductors may be located on the first surface **1805**, which also has the photodetectors **1802**. They may alternatively be located on the opposite surface of the support **1804**, such as by placing holes through the support **1804** using the focussed beam of a continuous wave or a pulsed laser such as a 10.6 μm carbon dioxide (CO_2) laser or a 1.06 μm Nd-YAG laser. Or, several layers of support material **1804** may be used similarly to the embodiment of FIG. **11** in order to make enough room to fit all the conductors. One electrode of each photodetector **1802** is connected to a common ground, such as through a transparent conducting layer disposed above the photodetectors **1802**.

As an alternative arrangement not shown in the Figures, each photodetector may be formed by several stacked layers of combined composite scintillator and photodiode material. In such embodiments, each layer of the laminated photodetector is first separately formed by disposing an inorganic material which is preferably at least about 100 μm thick on a support, and then curing it to form a semiconductor layer. The composite scintillators are then added to create indirect photodetectors. The composite scintillator has a thickness on the order of 100 μm, and the photodiode has a thickness on the order of about 10 μm, for a combined thickness of one layer of about 110 μm. About 10 layers stacked together in a laminate then has a thickness on the order of about 1 mm. The layers feed in parallel to a single set of electronics.

Once several slice elements **1801** have been made, a corresponding array **1800** may be assembled by stacking several slice elements **1801** together. This is illustrated in FIG. **19**, using four elements **1801** which corresponds to a four slice imaging apparatus **100**. Ideally the slices **1801** are slightly tapered, being thicker at the base than at the tip to "focus" them on the x-ray source **110**. Fiducial pins may extend through aligning fiducial holes **1811** (FIG. **18**) in each slice element **1801**, to properly position each element **1801** within the array **1800**.

FIG. **20** shows a slice element **2001** suitable for a spectral CT imaging apparatus. Accordingly, the element **2001** corresponds to a single imaging slice, which when stacked with other similar elements **2001** in the manner described in connection with the embodiment of FIGS. **18** and **19** forms a system **2000** (not shown) for imaging. The slice element **2001** includes several photodetectors **2002** and corresponding composite scintillators **2003** deposited on a first side **2005** of a support **2004**, perhaps in groups **2006**. For ease of illustration, the individual photodetectors **2002** and composite scintillators **2003** of only one group **2006** are shown in FIG. **20**. The photodetectors **2002** and composite scintillators **2003** as shown in the Figure are sectorial in shape, although any shape may be used. The cross-sectional size of the scintillators **2003** from the standpoint of the incoming radiation R is preferably on the order of approximately 0.5 to 5 mm by 0.5 to 5 mm, and most preferably approximately 1 mm by 1 mm. The size of the photodetectors **2002**, in relation to the size of the other components in the slice element **2001**, has been greatly exaggerated in FIG. **20** for purposes of illustration. In an actual slice element **2001**, for example approximately forty-two groups **2006** would span the arc length of the support **2004**, instead of the thirteen groups **2006** shown in the Figure.

Each of the groups **2006** in a first (remote) array **2012** of photodetectors **2012** incorporates higher energy composite scintillators, while the second (closer) array **2014** incorporates lower energy composite scintillators. Also, in comparison with the components of the first array **2012**, the scintillators and photodetectors of the second array **2014** are slightly smaller in size, with slightly smaller separations. This permits the second array **2014** to be mounted above the first array **2012**, and still be appropriately focused on the source of the incoming radiation R.

In yet further embodiments, one or more combined composite scintillator/inorganic photodiode layers may be tilted at an angle to the x-ray beam **112** to increase its effective thickness and thus reduce the number of laminations required to absorb the x-rays. A representative array **2100** is shown in FIGS. **21** through **23**. As shown in FIG. **21**, a support **2101** has photodiodes **2102** printed on it, as described above. A layer of composite scintillator or an x-ray intensifying screen **2150** is then placed on top of the photodetectors **2102**. The composite scintillator or image intensifying screen **2150** may be optically coupled to the photodiodes **2102** such as for example by using an optical adhesive. The composite scintillator or screen **2150** is then scribed to form gaps **2170**, as shown in FIG. **22**. The array is then folded fanwise at the gaps **2170** into a concertina shape, such as shown in FIG. **23**, and incorporated into a data measurement system. (The scale as shown in FIGS. **21** and **22** is greatly magnified with respect to the scale of FIG. **23**.)

The invention has been described with reference to the preferred embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof. The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the invention.

Having thus described the preferred embodiments, the invention is now claimed to be:

1. An imaging system comprising:

a radiation source which rotates around a central z-axis of the imaging system to perform imaging scans; and

an inorganic photodetector array including several discrete inorganic photodetectors arranged on a curved support, such that each row of inorganic photodetectors is aligned along the curve of the curved support, and each column of inorganic photodetectors is aligned in parallel to the central z-axis of the imaging system, wherein conductor paths are disposed along a distal surface of the curved support which is substantially opposite a surface of the support on which the inorganic photodetectors are disposed, and further comprising holes in the support filled with a conductor material different than the conductor path to electrically connect the conductor paths to the inorganic photodetectors, wherein the conductor paths associated with a column of inorganic photodetectors are located along the distal surface of the support opposite the column of inorganic photodetectors to a side of the inorganic photodetector array.

2. The imaging system of claim **1**, wherein the inorganic photodetectors comprise at least one of CIGS, $AuInGaSe_2$, and $AuInThSe_2$.

3. The imaging system of claim **1**, wherein the curved support comprises a bendable sheet.

4. The imaging system of claim **3**, wherein the bendable sheet comprises a PET sheet, a polyimide sheet, a PEET sheet, or a nylon sheet.

5. The imaging system of claim **1**, wherein each row of inorganic photodetectors corresponds to a single imaging slice during imaging scans performed by the imaging system.

6. The imaging system of claim **1**, further comprising one or more scintillators disposed between the radiation source and the inorganic photodetectors.

7. The imaging system of claim **6**, wherein the scintillators are formed from a composite scintillator material.

8. The imaging system of claim **1**, wherein the inorganic photodetectors are disposed on the curved support by a printing process.

9. The imaging system of claim **1**, the inorganic photodetectors operatively connectable via said conductor paths to one or more active electronic components disposed on the curved support.

10. The imaging system of claim **9**, wherein the curved support is comprised of more than one layer including a top layer and one or more under-layers, the inorganic photodetectors are disposed on the top layer, and each under-layer comprises a top surface which is proximate to the top layer and on which is disposed at least one of the conductor paths.

11. The imaging system of claim **1**, wherein the curved support extends around a complete circumference of the central z-axis of the imaging system.

12. The imaging system of claim **1**, wherein the inorganic photodetector array comprises two layers of inorganic photodetectors, a first layer associated with one or more high energy inorganic photoelectric materials, and a second layer associated with one or more low energy inorganic photoelectric materials.

13. The imaging system of claim **1**, wherein the inorganic photodetector array comprises at least two sectorial-shaped elements in a stacked relationship with each other, with several discrete inorganic photodetectors arranged on the sectorial-shaped elements.

14. The imaging system of claim **1**, wherein the inorganic photodetector array comprises a bendable inorganic photodetector array, the array comprising a bendable support, one or more active electronic components disposed on the support, and conductor paths operatively connecting each of the inorganic photodetectors to at least one of the active electronic components.

15. The imaging system of claim **14**, wherein the inorganic photodetectors are arranged in rows and columns on the bendable support, each row of inorganic photodetectors corresponds to a single imaging slice during imaging scans performed by an imaging system, and the columns are aligned in parallel to a central z-axis of the imaging system.

16. The imaging system of claim **14**, wherein the inorganic photodetectors comprise at least one of CIGS, $AuInGaSe_2$, and $AuInThSe_2$.

17. The imaging system of claim **14**, wherein the bendable support comprises a PET sheet, a polyimide sheet, a PEET sheet, or a nylon sheet.

18. The imaging system of claim **14**, further comprising composite scintillators disposed on top of the inorganic photodetectors.

19. The imaging system of claim **14**, wherein the assembly is mounted on a cradle within an imaging system to form an imaging data measurement system.

20. The imaging system of claim **14**, wherein the inorganic photodetectors are disposed on the support by a printing process.

21. The imaging system of claim **14**, wherein the conductor paths are disposed on a common surface of the bendable support with the inorganic photodetectors.

22. The imaging system of claim **14**, wherein the conductor paths are disposed on a distal surface of the support substantially opposite a surface on which the inorganic photodetectors are disposed, and the support comprises holes filled with a conductor material to electrically connect the conductor paths to the inorganic photodetectors.

23. The imaging system of claim **22**, wherein the support is comprised of more than one layer including a top layer and one or more under-layers, the inorganic photodetectors are disposed on the top layer, and each under-layer comprises a top surface which is proximate to the top layer and on which is disposed at least one of the conductor paths.

24. The imaging system of claim **14**, wherein the bendable support has a length which is approximately equal to an entire circumference surrounding a central z-axis of the imaging system, for use in a fourth generation imaging system.

25. The imaging system of claim **14**, wherein the inorganic photodetector array comprises two layers of inorganic photodetectors, a first layer associated with one or more high energy inorganic photoelectric materials, and a second layer associated with one or more low energy inorganic photoelectric materials.

26. The imaging system of claim **14**, further comprising one or more fiducial apertures disposed in the bendable support.

27. The imaging system of claim **1**, wherein a plurality of the conductor paths on the distal surface route opposite an area of one inorganic photodetector.

28. The imaging system of claim **27**, wherein at least seven conductor paths on the distal surface route opposite the area of one inorganic photodetector.

29. The imaging system of claim **1**, further comprising a common ground connected to a plurality of inorganic photodetectors.

30. The imaging system of claim **29**, wherein the common ground comprises a conductive layer disposed above the photodetectors.

31. The imaging system of claim **1**, wherein a conductor forms a base of each hole.

32. The imaging system of claim **1**, wherein the conductor material comprises a conductive adhesive.

33. A method of making an inorganic photodetector array for use in an imaging system, the method comprising:

disposing several discrete inorganic photodetectors on a front surface of a curved support;

placing one or more active electronic components on the distal surface of the support;

forming conductor paths along the distal surface of the support;

forming holes in the curved support; and

filling said holes with a conductor material different than the conductor path operatively connecting each of the inorganic photodetectors to at least one of the active electronic components;

wherein the conductor paths associated with a column of inorganic photodetectors are located along the distal surface of the support opposite the column of inorganic photodetectors.

34. The method of claim **33**, wherein the curved support comprises a bendable support.

35. The method of claim **34**, further comprising forming one or more composite scintillators into scintillator arrays above the inorganic photodetectors on the support.

36. The method of claim **35**, further comprising casting a composite scintillator block over the inorganic photodetectors and curing the composite scintillator block.

37. An imaging system comprising:

a radiation source which rotates around a central z-axis of the imaging system to perform imaging scans; and

an inorganic photodetector array including several discrete inorganic photodetectors arranged on a curved support, such that each row of inorganic photodetectors is aligned along the curve of the curved support, and each column of inorganic photodetectors is aligned in parallel to the central z-axis of the imaging system, wherein conductor paths are disposed on a distal surface of the curved support which is substantially opposite a surface of the support on which the inorganic photodetectors are disposed, and further comprising holes in the support filled with a conductor material different than the conductor path to electrically connect the conductor paths to the inorganic photodetectors, wherein the conductor material comprises a conductive adhesive.

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